DESIGN AND DEVELOPMENT OF A GENERIC ARCHITECTURE FOR APPAREL MANUFACTURING:

Volume VI, Additional Reports and Papers

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13. ABSTRACT *(Maximum 200 words)*

Research has been carried out to design and develop a generic architecture for an apparel enterprise that can serve as a blueprint for a computer-integrated apparel enterprise (CIAE). The Apparel Manufacturing Architecture (AMA) -- the first comprehensive architecture for manufacturing -- has been developed and validated in close collaboration with the apparel industry. AMA consists of a set of models the core of which is the *information* model which defines the schema of the shared information base for an apparel enterprise. The *function* model component of the architecture specifies how the activities carried out in an apparel manufacturing enterprise interact with each other through the shared information base. The third component of AMA, the *dynamics* model, describes how the interactions among the enterprise activities take place over time. The Recruit Induction Center Architecture (RICA) models the uniform distribution process at the Recruit Induction Center (RIC).

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Oxford Slacks, Monroe, Georgia, served as the first industry partner on the effort and contributed significantly to the development of the initial version of the Apparel Manufacturing Architecture. The various individuals at Oxford Slacks -- especially Ms. Melissa Bailey, Mr. Wilbur Holloman and Mr. Larry Johnson -- deserve sincere thanks and appreciation for their participation in the research.

Subsequently, the American Apparel Manufacturers Association (AAMA) and several member companies of AAMA participated in evaluating and validating the architecture and deserve thanks.

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* * *

Executive Summary

The Final Technical Report for the project entitled "Design and Development of a Generic Architecture for Apparel Manufacturing" is being submitted in seven volumes. The scope of the individual volumes is as follows:

Volume 0 Executive Summary Technical Report
[SJ-TR-ARCH-9603]

Volume I AMA Primer
[SJ-TR-ARCH-9412]

Volume II Apparel Manufacturing Architecture: The Function Model
[SJ-TR-ARCH-9412]

Volume III Apparel Manufacturing Architecture: The Information Model
[SJ-TR-ARCH-9412]

Volume IV Recruit Induction Center Architecture: Function and Information Models for the Uniform Distribution Process
[SJ-TR-ARCH-9411]

Volume V Research Methodology
[SJ-TR-ARCH-9603A]

Volume VI Additional Reports and Papers (**This Volume**)
[SJ-TR-ARCH-9603B]

* * *

Customer-Driven Uniform Manufacturing: The Roles of Advanced Information and Manufacturing Systems and Technologies

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Abstract

New recruits to the US Armed Forces come to recruit induction centers (RIC) for basic training which lasts for 6-11 weeks depending on the military branch. Upon arrival at the RIC, they are issued work clothes (e.g., utility trousers) and when they graduate at the end of the training period they leave with a complete issue of dress uniforms, among other things. The uniform supply and issuance process is currently designed by the US Defense Logistics Agency (DLA) to maintain adequate inventories of clothing items (at supply depots and RICs) such that there are no shortages at the RICs. To reduce these inventory levels and the overall cost of the uniform issuance process, DLA has a major program initiative underway that calls for the design and implementation of a customer-driven uniform manufacturing (CDUM) system. In this paper, the roles of the apparel manufacturing architecture (AMA) and the RIC architecture in the successful implementation of a CDUM system are discussed. An end-to-end process/product life-cycle approach is used to demonstrate the applicability of the results from the various research endeavors sponsored by DLA for realizing CDUM.

1. INTRODUCTION

New recruits to the US Armed Forces come to recruit induction centers (RIC) for basic training which lasts for 6-11 weeks depending on the military branch. Upon arrival at the RIC, they are issued work clothes (e.g., utility trousers) and when they graduate at the end of the training period they leave with a complete issue of dress uniforms, among other things.

Figure 1 shows the existing or *AS IS* end-to-end process in the supply of garments to RIC. When the inventory level at a RIC reaches the *reorder point*, the RIC places an order with the Defense Personnel Support Center (DPSC) in Philadelphia, PA. In turn, DPSC sends a requisition to its Depots to release the required goods to RIC. At the same time, orders are placed with DPSC apparel contractors to replenish the inventory at Depots. Upon receiving the delivery order from DPSC, the apparel manufacturer procures the necessary fabrics and trim from its suppliers, produces the garments and ships them to the Depots and/or RIC. Since the uniforms are supplied in standard sizes, they are altered at the RIC to ensure the right fit for the recruits.

The flow of both physical entities and information entities in the end-to-end process is shown in the figure. Currently, the information flow (e.g., purchase order, invoice, order status) involves voice and paper and is through telephone, mail and/or facsimile.

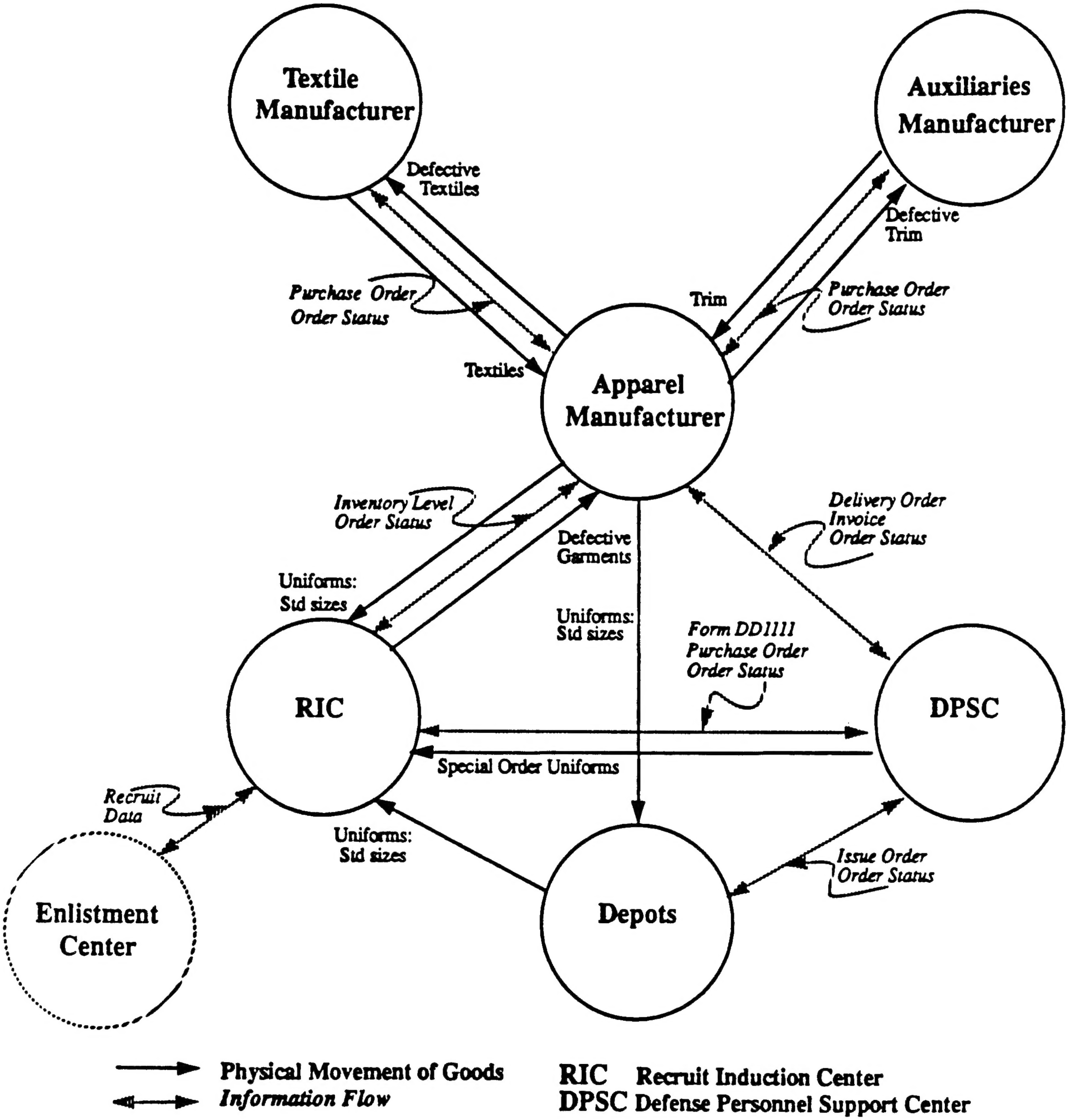

Figure 1. Clothing the Armed Forces Recruit: The *AS IS* End-to-End Process

Special Orders: However, if a recruit's uniform size falls outside the range of sizes stocked at the RIC, a request for a special order of uniforms is sent to DPSC along with the appropriate measurements using FORM DD 1111 as shown in the figure. The garments are custom-manufactured in the apparel factory at DPSC and shipped to the RIC for issuance to the recruit.

Thus, the entire uniform supply and issuance process is currently designed by the US Defense Logistics Agency (DLA) to maintain adequate inventories of clothing items at Depots and RICs so that requirements are properly met.

1.1 Analysis of the *AS IS* Process

A careful analysis of the *AS IS* end-to-end process reveals the following:

(i) To avoid shortage of uniforms at the RIC, the inventory levels in the pipeline (i.e., at Depots and RICs) tend to be high resulting in excessive holding costs; moreover, since the Armed Forces are continually evaluating and modifying the garment styles and specifications, the large time lag between procurement and issuance may render some of the uniform styles obsolete at the time of issue.

(ii) Since dress uniforms are procured in a set of standard sizes, they have to be altered to correctly fit the individual recruit, thereby further increasing the final cost of the uniforms; a recruit with an ill-fitting uniform will typically not be graduated by the RIC.

(iii) Almost all the existing communication (shown in broken lines in Figure 1) between the various nodes in the chain -- RIC, DPSC, Depot, Apparel Manufacturer -- is through voice, mail and/or facsimile.

(iv) Although the recruits are measured at Enlistment Centers when they are accepted into the Armed Forces, these measurements (height, weight, chest, etc.) are not made available to the RICs.

1.2 Opportunities for Improvement: The *TO BE* Process

Figure 2 shows the *TO BE* end-to-end process in the production and distribution of uniforms to recruits at RIC. The major opportunities for improving the *AS IS* process are presently discussed.

Electronic Interconnection and Data Interchange in the Chain: As shown in Figure 2, all the channels (shown in broken lines in the figure) can be used for electronic data interchange (EDI) in the end-to-end process. The advantages of EDI include timely, fast and more accurate exchange of information. With the advent of easy-to-use EDI systems and the

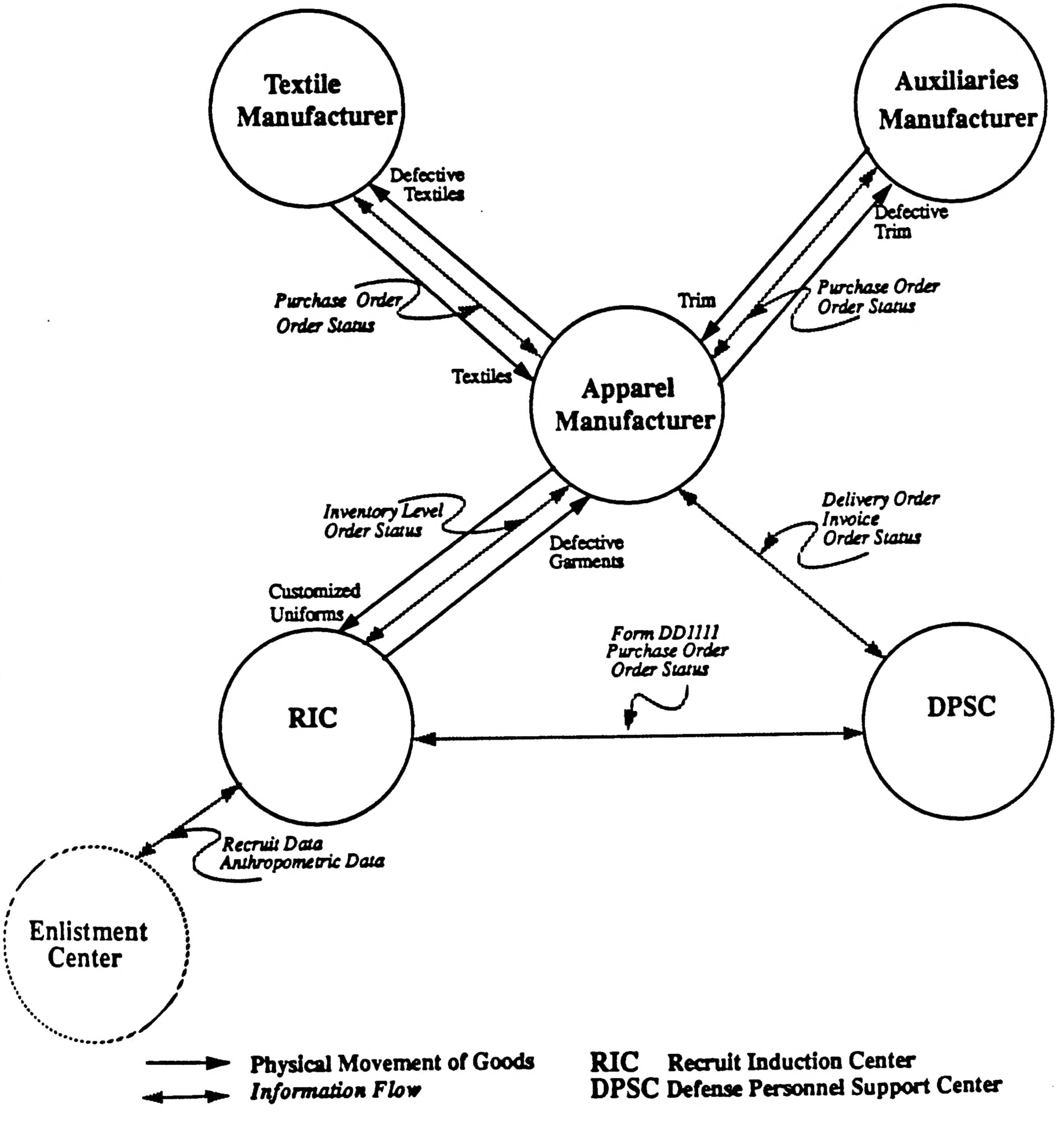

Figure 2. Clothing the Armed Forces Recruit: The *TO BE* End-to-End Process

proposed national *information superhighway*, the necessary information infrastructure will be available for implementing EDI in the end-to-end process.

Effective Utilization of Data: In the commercial world, the point-of-sale (POS) data gathered in the retail store enables the apparel producer to track a product's performance and to effectively respond to the trend -- produce items that are selling fast, discontinue others, modify styles and change fabric colors. The same approach can be adopted to replenish the RIC inventory: After receiving work and dress uniforms at the RIC, recruits enter the issue information in Data Sheets (e.g., Bubble Charts) as shown in Figure 3. If this data is electronically recorded at RIC, it can be used in the same way as the POS data is used in the commercial world. The information can then be transmitted electronically to DPSC and to the apparel manufacturer; the latter can utilize the information to better schedule production to meet the demands. In short, the customer's demands can *drive* the various actions in the product chain and therein lies the underlying philosophy of the CDUM Initiative.

The CDUM Initiative: When the CDUM Initiative is fully operational, the RICs will share the RIC issue data with the apparel contractors who in turn will plan their operations (production, ordering materials from fabric and trim manufacturers) to produce and deliver uniforms on time.

As an integral part of the CDUM Initiative, if the Enlistment Centers transmit anthropometric data on a recruiting class (along with other data) to the various RICs (and eventually the apparel contractor, Figure 2) prior to, or at the beginning of, the training program, the uniforms can be *customized* and delivered to the graduating recruits on time, thereby reducing or even *eliminating* alteration costs. The inventory levels at the RICs can also be better managed and stock-outs can be minimized.

The apparel contractor will be responsible for assuring the quality of the garments: just as a commercial customer can take a defective garment to the retail store for a full refund or exchange, a RIC can return defective garments to the suppliers for full reimbursement or replacement. Yet another major difference between the *AS IS* and *TO BE* scenarios will be the elimination of Depots and special order uniforms. DPSC will play a key role as the information nerve center in the *TO BE* end-to-end process that will be characterized by the practice of *electronic commerce* (EC).

1.3 A Systems Approach to CDUM Implementation

An overall *systems* or fundamental approach to studying and modeling the end-to-end process is critical for the successful implementation of CDUM. The first step is to *understand* and *represent* the various processes and information flows in the end-to-end process shown in Figure 2. Once such a model or *architecture* is developed, it can be used as the framework for identifying the necessary transformations in -- (i) information systems and technologies including EDI; (ii) process technologies including flexible automation; and (iii) business and

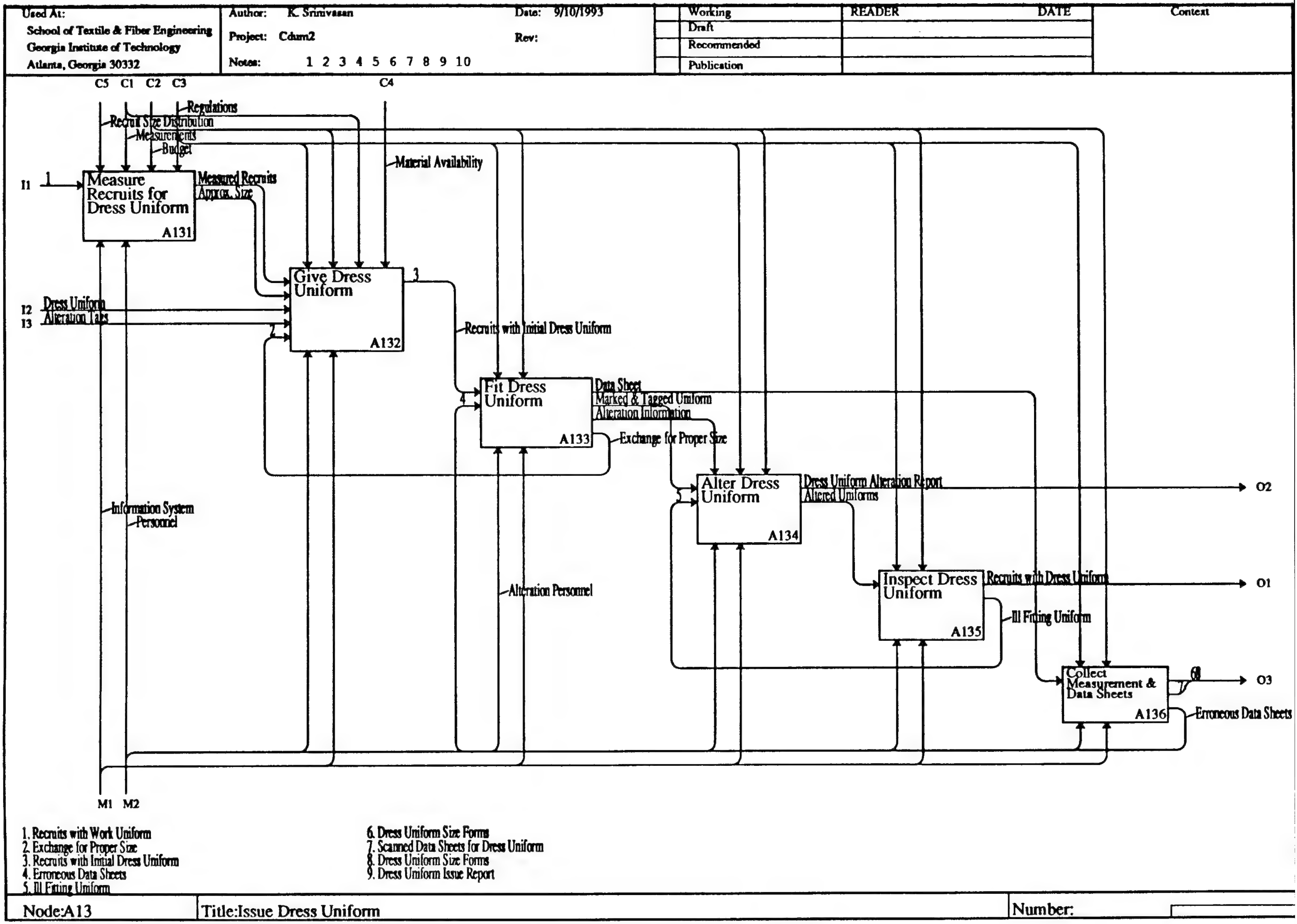

Figure 3. Uniform Issue Data is Recorded in Activity A136 (RIC)

work practices -- to achieve the desired goal of supplying RICs on demand, the *TO BE* scenario.

The remainder of the paper is organized as follows: The critical roles of information, process technologies and business practices in the implementation of CDUM are discussed in Section 2. In Section 3, brief overviews of the apparel manufacturing architecture (AMA) and RIC architecture are presented; these are then used to identify and "place" the various research efforts in progress that will facilitate CDUM. A few concluding remarks are presented in Section 4.

2. INFORMATION, PROCESS TECHNOLOGIES AND BUSINESS PRACTICES

Information is the lifeblood of any enterprise, especially under the CDUM scenario, where production and inventory replenishment (garment type, quantity and size range) will be *driven* by the demand [3]. Likewise, in the end-to-end process, if the fabric manufacturer transmits information on the fabric quality along with the fabric, the apparel manufacturer can utilize it to optimize the cutting operation. Defective fabric part[s] can be prevented from reaching the sewing floor and wasteful *value-adding* operations can be avoided since the resulting garment will not meet the requirements of the customer. Thus, information can be utilized to improve the quality of the final product while reducing the overall costs.

As apparel operations become distributed, i.e., sets of operations on a garment are performed in different geographical locations, timely access to information becomes critical to maintain work-in-process levels within reasonable limits and to manufacture products on schedule. Coordination and production scheduling are highly complicated due to the difficulty of bringing corresponding component subassemblies together at the *right* time and in the *right* quantities from different sites. Thus, timely access to the right information again becomes critical for not only meeting the production schedule but also for keeping the operators fully utilized in the plants and finally, being responsive to the needs of the Department of Defense (DoD).

In short, access to the *right* information at the *right* time is essential for making the *right* decisions throughout the end-to-end process. To facilitate this seamless electronic interchange of information and to implement advanced information and manufacturing systems and technologies required for CDUM, there is a critical need for information engineering viz., identifying, analyzing, synthesizing and structuring information entities and their flows in the end-to-end process.

2.1 CDUM and Advancements in Process Technologies

Advances in process technologies will enable the apparel industry to adopt more efficient techniques, reduce the manufacturing time and meet regular and unanticipated surge demands from RICs. Advances in process technologies also contribute to improved product quality and performance. For example, the cut parts produced by a numerically controlled cutter are less

prone to the *cutter lean* problem than those produced manually. Technological advances also upgrade the job levels of operators, thereby enhancing the overall work atmosphere.

There are two major types of automation: fixed and flexible. The former is well-suited for producing high volume items of the same type faster, while flexible automation is the key to producing small-lot items with a minimum of changeover time: both types of automation are critical to CDUM: A majority of the uniforms issued at RICs are in standard sizes for which fixed automation would be appropriate. However, when there are recruits whose physical dimensions require non-standard sizes, the equipment must be quickly reconfigured to meet the demand; this calls for flexible automation.

Traditionally, machines on the apparel shop-floor have been viewed as serving one function, viz., producing subassemblies. However, this view must change if the industry is to be responsive to its customers, both civilian and military. The machines must serve as focal points or *nodes* for information acquisition and utilization in the enterprise. Features such as on-board intelligence (for troubleshooting), touch screen and graphic displays, and bi-directional communication must be built into the various machines (e.g., sewing, cutting, pressing) to create a truly computer-integrated manufacturing (CIM) environment. The concept of easily reconfigurable sewing machines (e.g., to quickly switch from sewing battle-dress uniform coats to civilian trousers) or multipurpose workstations should be explored and the necessary software/hardware technologies developed. The machines should also incorporate intelligent controls and sensors to minimize defects and reduce rework and/or product failure in the field.

2.2 CDUM and Business Practices

The ability of an apparel enterprise to harness the potential of all its employees is critical to the successful implementation of CDUM. Because Quick Response is an important aspect of CDUM, *risks* must be taken by the employees in formulating plans to take advantage of such business opportunities, be it creating new products or modifying existing processes to produce a better-quality product. The enterprise leadership must trust its employees and work with them as a team to develop company mission and goals. In short, management must *empower* its team members and encourage them to be innovative and take risks to meet the requirements of its customers. A well-trained, skilled, and empowered workforce must be built. Also, performance metrics and reward/compensation systems must be restructured to encourage team-, quality- and value-based compensation.

With planned downsizing of the US Armed Forces brought on by the end of the Cold War, DoD procurement needs are expected to decrease with time. This means apparel companies that have relied solely on military contracts need to explore diversification into the civilian market to survive in these times of reduced DoD budgets. They should adopt innovative business practices such as the *shared production* concept which calls for sharing production resources between a civilian customer and DoD [11]. Their survival is indeed critical to CDUM -- DoD cannot afford to lose the supplier base entirely and risk its readiness for global deployment at short notice.

2.3 Drivers and Enablers for CDUM

A responsive and truly computer-integrated apparel enterprise[1] (CIAE) that will deploy state-of-the-art manufacturing technologies, information and knowledge management techniques and systems, and innovative business practices will be at the heart of a CDUM System.

The major techniques or *drivers* for creating a CIAE are [3, 4, 5]:

- o Computer-Integrated Manufacturing
- o Integrated Product/Process Design (IP/PD) or Concurrent Engineering (CE)
- o Uniform Product Representation Standards (APDES)
- o Agile Manufacturing (AM)
- o Quick Response (QR)
- o Total Quality Management (TQM).

The *enablers* or means for successfully applying these techniques throughout the life-cycle of the end-to-end process are:

- o Enterprise Integration (EI)
- o Electronic Data Interchange (EDI)
- o Information Superhighway
- o Knowledge-Based Systems (KBS)
- o Information Engineering, Structured & Object-Oriented Analysis Tools
- o Automation and Robotics, including Intelligent Sensors.

Innovative business practices include the adoption of:

- o Dual Use or Shared Production Concepts [11]
- o Distributed Design and Manufacturing
- o Team-Based Work Practices and Compensation
- o Activity-Based Costing and Management (ABC, ABM).

Thus, it is clear that end-to-end process architecture and information systems, process technologies, and business practices are closely intertwined with access to the *right* information as the critical catalyst for the successful implementation of CDUM.

As part of the Defense Preparedness Authorization, DLA funded the establishment of advanced apparel manufacturing technology demonstration centers (AAMTDs) at Clemson University, Fashion Institute of Technology (FIT) and Georgia Institute of Technology, and has been sponsoring research at these centers and other universities on a variety of topics related to improving the state-of-the-art in apparel manufacturing [10].

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[1]A CIAE can be defined as an enterprise that utilizes computers for the engineering, planning, manufacturing, marketing and business functions of the enterprise, and for the integration of all these functions into a cohesive enterprise system through a common information/knowledge base.

3. CDUM: CONCEPT TO REALITY

The advancements from the various research endeavors sponsored by DLA at the AAMTDs that facilitate the successful transformation of the CDUM concept to reality are discussed in this section.

3.1 End-to-End Process Architecture

A prerequisite for the successful implementation and demonstration of CDUM is a detailed specification of the various activities carried out at each of the nodes in Figure 2. The principal modules are the Apparel Manufacturing Architecture (AMA), the Textile Manufacturing Architecture and the RIC Architecture that respectively model the apparel enterprise, the textile enterprise and the RIC.

Apparel Manufacturing Architecture: AMA is a comprehensive set of specifications for a computer-integrated apparel enterprise developed at Georgia Tech [1, 2, 8, 9] under research funding from the US Defense Logistics Agency. AMA consists of a set of models the core of which is the *information* model which defines the schema of the shared information base for an apparel enterprise. The *function* model component of the architecture (see Figure 4) specifies how the activities carried out in an apparel manufacturing enterprise interact with each other through the shared information base. The third component of AMA, the *dynamics* model, describes how the interactions among the enterprise activities take place over time. The USAF's IDEF Methodology [12] was used in the development of AMA. Moreover, it was developed in cooperation with major apparel manufacturers and a few member companies of the American Apparel Manufacturers Association (AAMA). AMA can thus play a significant role in the implementation of CDUM.

Yarn and Fabric (Textile) Manufacturing Architectures (YMA and FMA): The Yarn and Fabric Manufacturing Architectures are being developed at Georgia Tech under funding from the National Science Foundation. They model the activities (and underlying information entities and relationships) associated with the production of yarns and fabrics.

RIC Architecture: An *AS IS* architecture of the uniform distribution process at RICs has been developed at Georgia Tech [6, 7]. This was accomplished through discussions between a DoD Joint Working Group and RIC personnel during visits of the Group to major RICs around the nation. Figures 5 and 6 show the principal higher level activities in the uniform distribution process. Each of the activities has been decomposed to the desired degree of detail so that issues related to automating the individual processes can be examined.

Thus, the basic end-to-end process architecture is in place for the implementation of CDUM.

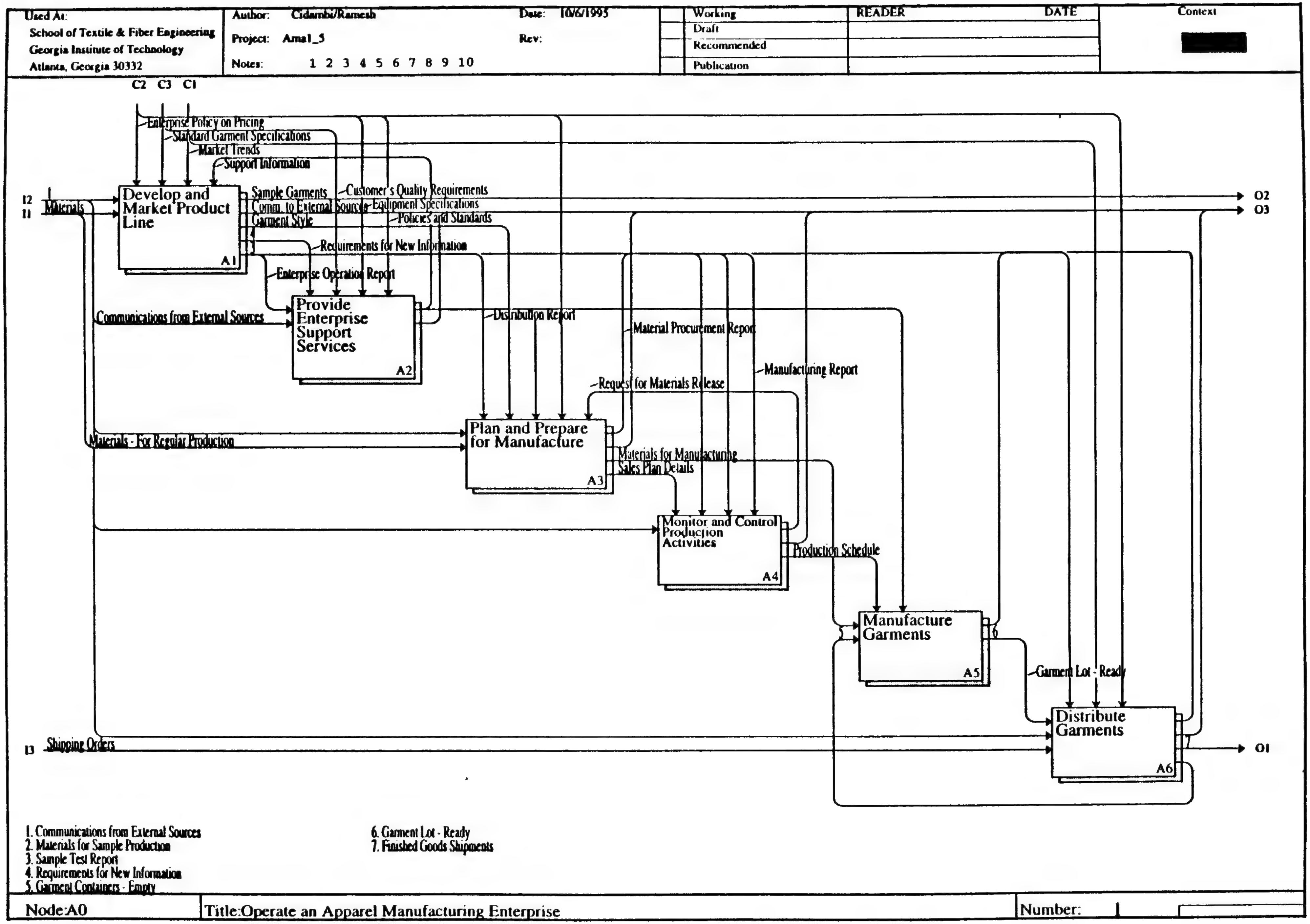

Figure 4. Top Level Activities in An Apparel Enterprise

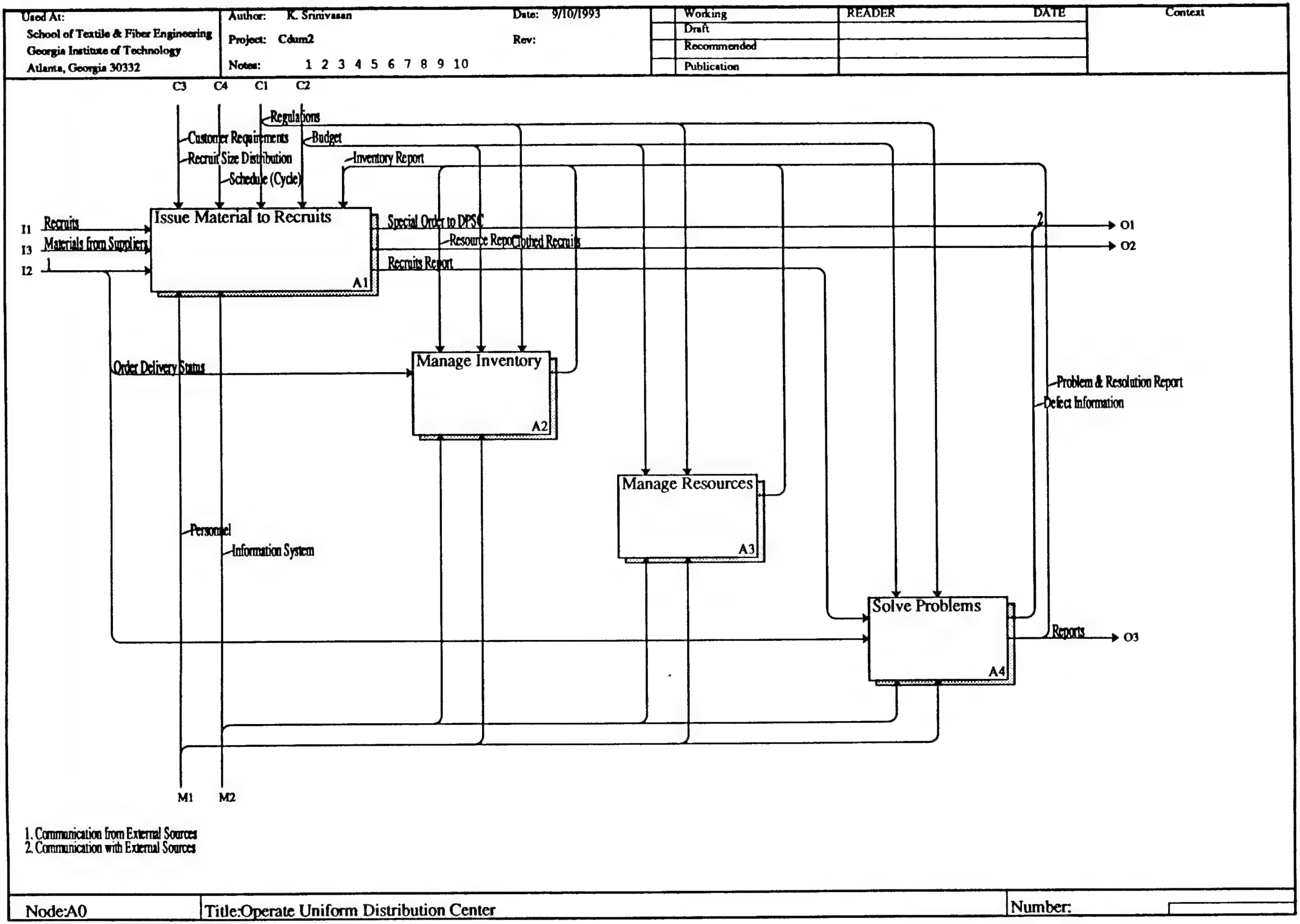

Figure 5. Top Level Activities in A Recruit Induction Center

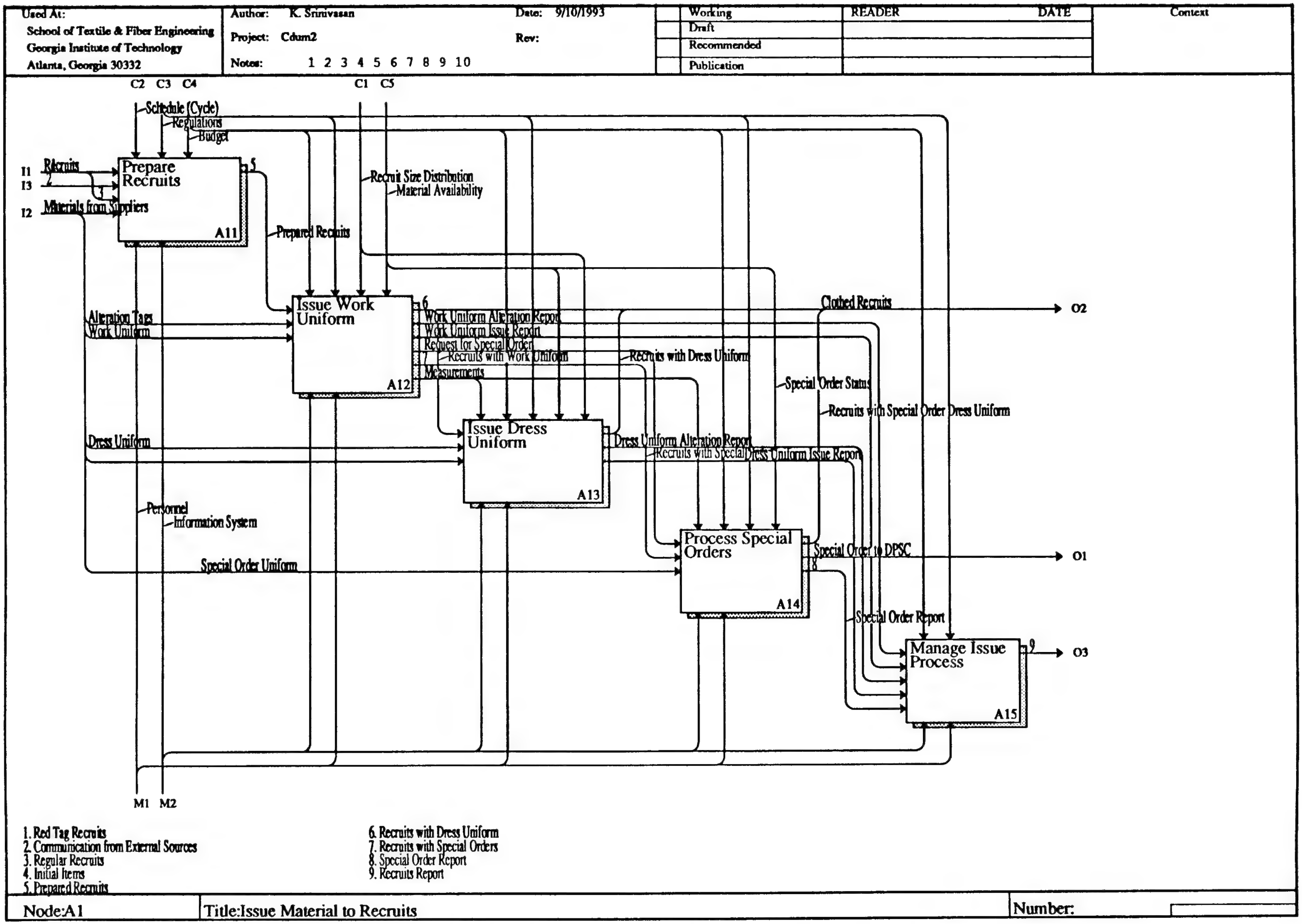

Figure 6. Principal Activities in Issuing Materials to Recruits at RIC.

3.2 Research Efforts and the End-to-End Process

The end-to-end process/product life-cycle approach is used in this section to demonstrate the applicability of the results from the various research endeavors. The principal activities can be classified into the following groups using the A0 diagram of AMA (Figure 4):

- Garment Design at the Armed Forces' Apparel Design Centers (Activity A1 in AMA)
- Vendor Selection at DPSC (Activity A3 in AMA)
- Pre-Production at Apparel Enterprise (Activities A2-A4 in AMA)
- Production at Apparel Enterprise (Activity A5 in AMA)
- Product Shipping and Distribution (Activity A6 in AMA)
- Uniform Issuance at RIC (Activity A1 in the RIC Architecture)

The various activities in the end-to-end process can also be grouped into three time-based phases, viz., (i) Garment Design and Vendor Selection; (ii) Start-up at Apparel Manufacturing Enterprise; and (iii) Steady State Operations. Table 1 attempts to map the various research efforts to the activities represented in AMA.

3.2.1 Phase I: Garment Design and Vendor Selection

In this first phase, a new garment may be designed for a specific purpose or an existing garment may be redesigned to conform to changing profiles of recruits (based on tracking historical anthropometric data from RICs) or to utilize new materials. Once a garment design has been finalized, DPSC must find vendors to supply the garments.

Garment Design Process: The principal activities in the garment design process are shown in the A12 diagram of AMA (Figure 7). The associated information entities and relationships in the AMA Information Model capture the required information for carrying out these activities. This part of AMA can be utilized by the design departments of the Armed Forces (e.g., Natick RD&E Center, Wright-Patterson AFB) to reengineer their design and specification preparation operations so that they can effectively meet their goals of continuously improving the fit and performance of the garments.

The three major garment redesign efforts, two at Clemson University for Air Force Shirts and Stitchless Chemical Protective Suits, and one at FIT for the Navy Peacoat come under the A12 activity of AMA, *Develop Garment Style*; the results from these efforts will be useful to the experts in the design departments of the Armed Forces engaged in product improvement activities.

Vendor Selection: Once a garment has been designed and adopted by the military, DPSC assumes the responsibility for procuring the garments in the required quantities. DPSC can use historical data from the RIC (for quantity and size ranges) to forecast product quantities. This data can be obtained electronically from the Enlistment Centers and RICs.

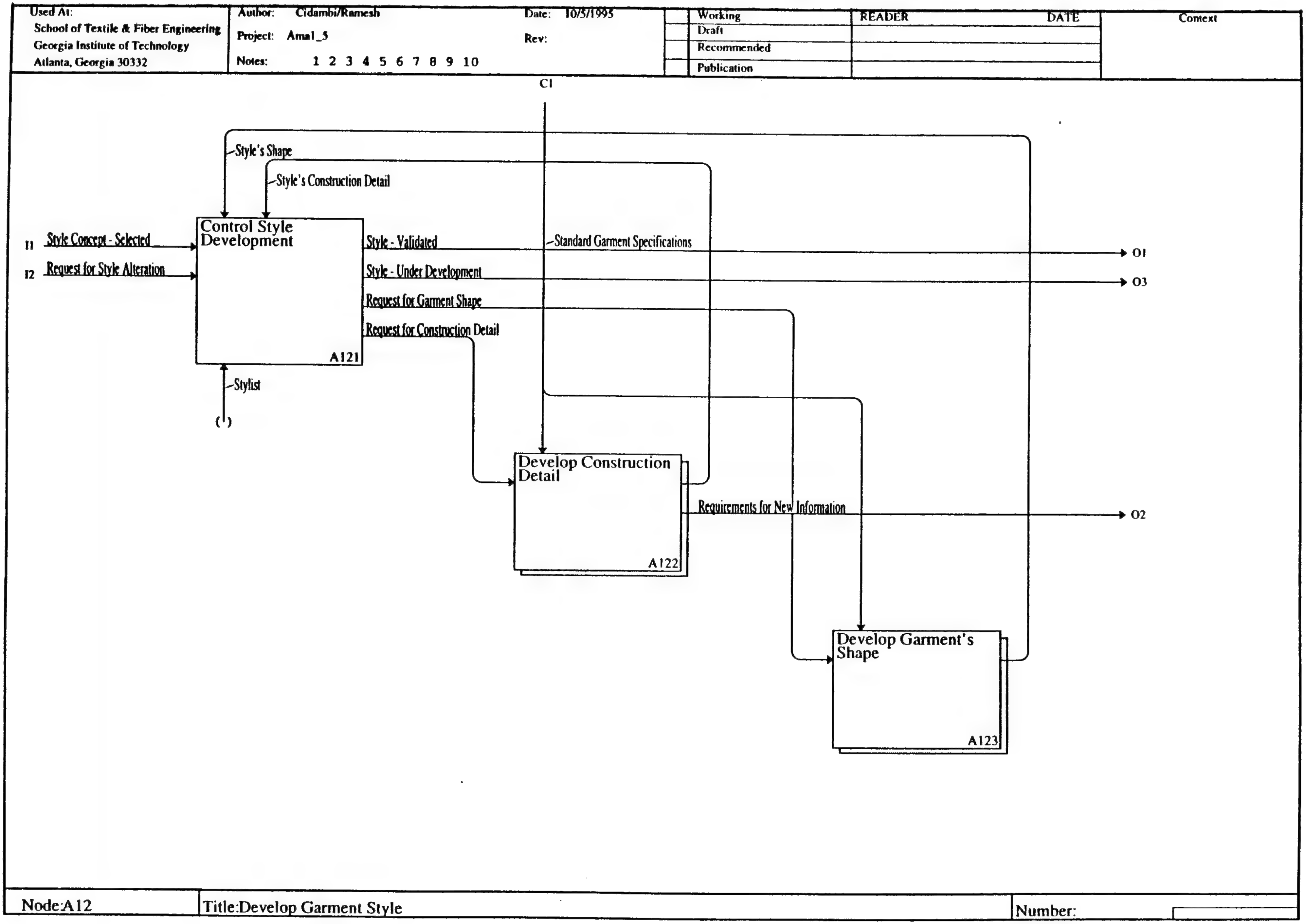

Figure 7. Product Design Activities in AMA.

The Bid Evaluation Software Tool (BEST) developed at Georgia Tech can be utilized by DPSC to apply a knowledge-based approach to selecting a suitable vendor -- activity A312 of AMA. The BESTForms in BEST can facilitate EDI and EC, and DPSC can utilize the information superhighway to set up a database of vendor capabilities that can be continuously updated. Moreover, the evaluation process for selecting contractors will be objective and will require considerably less time than the present.

DPSC - Apparel Enterprise Interface: Once a source has been selected, DPSC can transmit the patterns electronically to the successful contractor; NIST's Neutral File Format, developed as part of the APDES effort, can facilitate the interchange of patterns between several computer-aided design (CAD) systems being used in the apparel industry. Delivery schedules and order quantities can be transmitted electronically by DPSC. Invoices and delivery status information can also be processed electronically.

3.2.2 Phase II: Start-up at Apparel Manufacturing Enterprise

Once the order is received by the apparel manufacturing enterprise, the start-up phase commences and the enterprise must carry out the range of activities captured in A2 through A6 of AMA (see Figure 4).

Provide Manufacturing Support Services (A2): The enterprise must perform the following three major functions covered in the A2 diagram of AMA to provide the necessary support to the various operations in the enterprise:

- Establish Quality Control Practices (A21)
- Develop Suppliers for New Materials (A22)
- Maintain Manufacturing Resource Data (A23)

The apparel enterprise can use Clemson's Hypermedia project for retrieving product specifications to establish quality control practices (A21 activity) -- for the garment and raw materials -- to produce and deliver quality garments to the RIC. Then, the enterprise can utilize the underlying concepts in BEST to develop similar vendor evaluation programs to identify suppliers for new materials (A22); a database implementation of the corresponding segment of the AMA Information Model can facilitate the A23 activity of maintaining manufacturing resource data.

Plan and Prepare for Manufacture (A3): The next major activity in the enterprise involves planning and preparing for manufacturing and consists of the following four major tasks covered in the A3 diagram of AMA:

- Receive and Confirm Sales Order (A31)
- Pre-process Reorders (A32)

- o Complete and Release Program (A33)
- o Procure Materials (A34)

In receiving and confirming the sales order from DPSC, the apparel enterprise must select a manufacturing location to produce the garments. Depending on the available production capability and capacity, the enterprise may decide to subcontract a certain portion of delivery order. It can use BEST either to evaluate potential contractors or one of its own plants and eventually select a manufacturing location (A312 activity).

EDI linkages with its suppliers (textiles and trim in Figure 2) will facilitate the procurement of materials so that there are no shortages that might lead to delays in production and delivery to RICs. For inspecting, monitoring and controlling fabric quality (A343 activity), Clemson's Color Clustering System can be utilized in conjunction with Georgia Tech's FDAS (fabric defects analysis system) to ensure that only defect-free material is released by the A3433 activity.

Monitor and Control Production Programs (A4): The major activities in monitoring and controlling the production program in the enterprise to meet DPSC's delivery order are as follows:

- o Issue Production Orders (A41)
- o Plan Cutting and Spreading (A42)
- o Schedule Production (A43)

The enterprise can utilize Clemson's Hierarchical Production Planning and Scheduling System at the highest level to carry out part of the A4 activity. Gerber Garment Technology's advances in automated marker making coupled with intelligent pattern engineering can be effectively utilized for preparing markers (A421). The results from Georgia Tech's Cut Order Planning effort will help determine the spread layout (A423) so that the enterprise can optimize material utilization while producing the required quantities in the specified sizes.

Manufacture Garments (A5): To manufacture the garments, the apparel enterprise must carry out the following tasks:

- o Cut Fabric and Collect Garment Parts (A51)
- o Distribute Production Schedule (A52)
- o Produce Garments (A53)
- o Perform Quality Audit (A54)

The apparel enterprise can utilize Clemson's Fabric Inspection System using the Eagle Eye Color Surveillance System to inspect the fabric during spreading (A513). If this is interfaced with Georgia Tech's FDAS, a closed loop fabric defect detection and identification system can be deployed by the enterprise. The inspection results can be electronically communicated to the fabric supplier. Clemson's CCC can also be utilized in this task to ensure that the

spread is defect-free. Gerber Garment Technology's program for optimizing N/C cutter path can be used by the cutting department (A5132) so that productivity can be enhanced: a vital requirement for reducing final garment costs.

The assignment of production resources (A531) is a critical task in producing garments; for this, the enterprise can utilize results from both Clemson's Hierarchical Production Planning and Scheduling System and Florida's Production Planning and Scheduling System.

The enterprise can draw upon results from several research endeavors in the area of shop-floor operations, viz., the *Sew and Finish Garments* activity (A532). These include Clemson's Lookahead Simulation, Georgia Tech's Discrete Event Simulation, USL's CIM System and Georgia Tech's Cut Parts Inspection System. For transporting garment subassemblies (A5323), Clemson's AGV system can be deployed on the shop-floor. The relative merits of the bundle system, UPS and Flexible Workgroups have been investigated by Clemson and Georgia Tech. These results can be utilized to set up appropriate Sewing and Finishing Units (A53241) on the shop-floor.

The enterprise can incorporate defect detection devices being developed by Georgia Tech on the sewing machines so that no defects are produced in the sewing operation (A53242). Likewise, the enterprise can deploy the automation technologies being developed by Clemson and NCSU for sewing machines so that the machines become flexible to produce a variety of garments: a critical requirement to meet the demands for garments in non-standard sizes for recruits. If the enterprise employs physically challenged operators, Clemson's VAST system can be used to operate the sewing machines. The results from the ergonomics efforts at Georgia Tech and Clemson can be effectively utilized by the enterprise to create a conducive and safe working environment.

The shop-floor mechanics can use Clemson's Expert Maintenance System to ensure the smooth running of the various machines. Georgia Tech's SDAS (sewing defects analysis system) can be deployed for inspecting the finished garments (A541) and keeping track of defect rates on the shop-floor. The enterprise can utilize Clemson's results from the Shop-Floor Performance Metrics in conjunction with the Integrated Production Cost System for benchmarking purposes and to keep track of production costs even as the garments are being produced. In fact, the enterprise can utilize this data to suitably refine its operations in real-time.

Distribute Manufactured Garments (A6): The final activity in the end-to-end process at the apparel enterprise involves the distribution of the garments to the various RICs based on the delivery order issued by DPSC.

Enterprise Infrastructure: The various machines and technologies deployed in the apparel enterprise play a major role in meeting the requirements of RICs. The enterprise must continuously upgrade and enhance this infrastructure by taking advantage of advancements in technologies. Clemson's AMCIA and Georgia Tech's COMPASS can be utilized by the

apparel enterprise to evaluate various options based on a set of nontraditional criteria and make informed capital investment decisions; such an approach will enable the enterprise to utilize state-of-the-art technology in all its operations.

3.2.3 Phase III: Steady State Operations

Once the start-up phase is completed and the enterprise begins shipping garments to the RICs on a regular basis, the operations in the end-to-end process reach a steady state. By implementing a total EDI system, the issue data can be continuously communicated by the RIC to the apparel enterprise; the latter can utilize it to regulate its production so that the inventory levels in the pipeline are minimized and the RIC doesn't experience any shortages. Requests for special orders can be electronically communicated to the apparel enterprise which can in turn employ flexible sewing machines to quickly reconfigure the processes and meet the requirements on time. By electronically linking the Enlistment Centers with RICs, the complete end-to-end process can effectively utilize the information superhighway.

4. CONCLUDING REMARKS

The CDUM Initiative underway at DLA for supplying uniforms to RICs is aimed at adopting the commercial practice of customer- or demand-driven replenishment of inventory. The role of an end-to-end process architecture in implementing CDUM has been discussed. An end-to-end process/product life-cycle approach has been used to demonstrate the applicability of the results from the various research endeavors sponsored by DLA for realizing CDUM. The end-to-end process architecture can be effectively utilized to identify research opportunities to further the CDUM concept. If the participating apparel enterprise deploys the technologies emerging from the broad range of research efforts sponsored by DLA, the CDUM concept can indeed become an operating reality! And any commercial apparel enterprise aiming to be truly responsive to its customer's needs and operate in a Quick Response mode can similarly reengineer itself and compete successfully in the global market.

Acknowledgments

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COMPUTER-AIDED DESIGN AND MANUFACTURING: A TEXTILE-APPAREL PERSPECTIVE[1]

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ABSTRACT. Today's textile-apparel industrial complex is characterized by a multitude of conflicting demands: smaller lot sizes, increased product flexibility, higher product quality and decreasing delivery times. The textile/apparel industry must deploy state-of-the-art manufacturing and information management techniques to operate successfully in such a demanding and highly competitive global market. In this context, the role and scope of mechatronics in textile-apparel production systems are discussed with specific examples. The need for techniques and tools such as information engineering, electronic data interchange and knowledge-based systems technology is established and their relevance to the textile-apparel complex is discussed. An overview of major research endeavors including the development of an enterprise architecture, knowledge-based systems and product data standards is presented. Finally, some topics for further research in areas ranging from distributed design and manufacturing to the development of product data exchange standards are proposed.

1. Introduction

Today's textile-apparel industrial complex is characterized by a multitude of conflicting demands: smaller lot sizes, increased product flexibility, higher product quality and decreasing delivery times. To operate successfully in such a demanding and highly competitive global market, the textile/apparel industry must deploy state-of-the-art manufacturing and information management techniques; the major techniques are Computer-Integrated Manufacturing (CIM), Concurrent Engineering (CE), Design for Manufacturability (DFM), uniform product representation standards, Just-in-Time (JIT) manufacturing, Quick Response (QR) and Total Quality Management (TQM). The tools or means for successfully applying these techniques throughout the life-cycle of the textile/apparel domain are automation, robotics, computers, electronic data interchange (EDI), knowledge-based systems (KBS), information engineering, and structured analysis and design tools (SADT). In other words, the key lies in successfully integrating mechanical (or physical) elements of the system with the electronic (or information) components.

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1.1 MECHATRONICS AND THE TEXTILE-APPAREL COMPLEX

Mechatronics, a term coined by Japanese researchers, is commonly defined as the efficient integration of mechanical and electronic engineering to create an optimum product. The ultimate objective of any enterprise is to produce the *right* product, of the *right* quality, in the *right* quantity, at the *right* price and at the *right* time (the five *R*s of a manufacturing enterprise) [7]. The application of the mechatronics philosophy, viz., the effective utilization of state-of-the-art technology (be it mechanical or computing) in all facets of its operation -- design, development, planning, production, distribution, marketing and business -- will enable the enterprise to achieve its goals in the highly dynamic and competitive global market.

1.1.1 Integration and the Textile-Apparel Complex: An enterprise that effectively integrates the various functions through a common information/knowledge base is generally referred to as a Computer-Integrated Enterprise (CIE) [9]. The key to achieving a computer-integrated-textile-apparel complex lies in a careful study and adoption of the principles of mechatronics by the industry. Moreover, to achieve true integration, the traditional lines that have separated the major components or building blocks (fibers, textiles and apparel) must disappear.

The word *integration* is used in a broader context than just physical proximity or co-location. Figure 1 shows the three major functions associated with a typical scenario in the textile-apparel life-cycle. The *product design* activity may be physically located in any of the major fashion centers of the world, viz., Milano, Paris or New York; the plant to carry out the *product manufacturing* function may be located in Greenville, Hong Kong or Biella, and *product marketing* can take place in retail stores around the world from London to Tokyo. As lead times become shorter and demand for product variety increases, coordination and control -- or *conceptual integration* -- of the three major activities become critical. It is therefore clear that mechatronics has a vital role to play in the textile-apparel complex.

In this Chapter, the state of the textile-apparel industrial complex vis-a-vis the mechatronics philosophy is examined. In Section 2, specific applications of mechatronic elements in textile-apparel production systems are discussed. In Section 3, the roles of information engineering, electronic data interchange and knowledge-based systems technology in developing mechatronic solutions are discussed. Ongoing research activities and scope for further research efforts are covered in Section 4. Finally, some concluding remarks are presented in Section 5.

2. Mechatronics and Textile-Apparel Production Systems

Figure 2 shows a detailed view of the interrelationships between the three major functions in the textile-apparel complex. Two major types of entities flow through, and are processed by, the functions. They are *physical* entities such as fabrics and garments, and *information* entities such as design specifications and market trends. The flow of physical entities is predominantly in a single or forward direction (denoted by thick lines in the figure). In contrast, the flow of information entities is bidirectional (thin lines in the figure). In fact, as the industry becomes increasingly driven by what the consumer wants and demands, i.e., consumer-driven design and manufacturing (CDDAM) becomes the accepted norm in the industry, the information flow in the reverse direction (from the consumer to the manufacturer and designer) will assume greater importance. And the ability of an enterprise to successfully utilize this and other information to rapidly reconfigure itself -- change designs, fabrics, styles, production and marketing

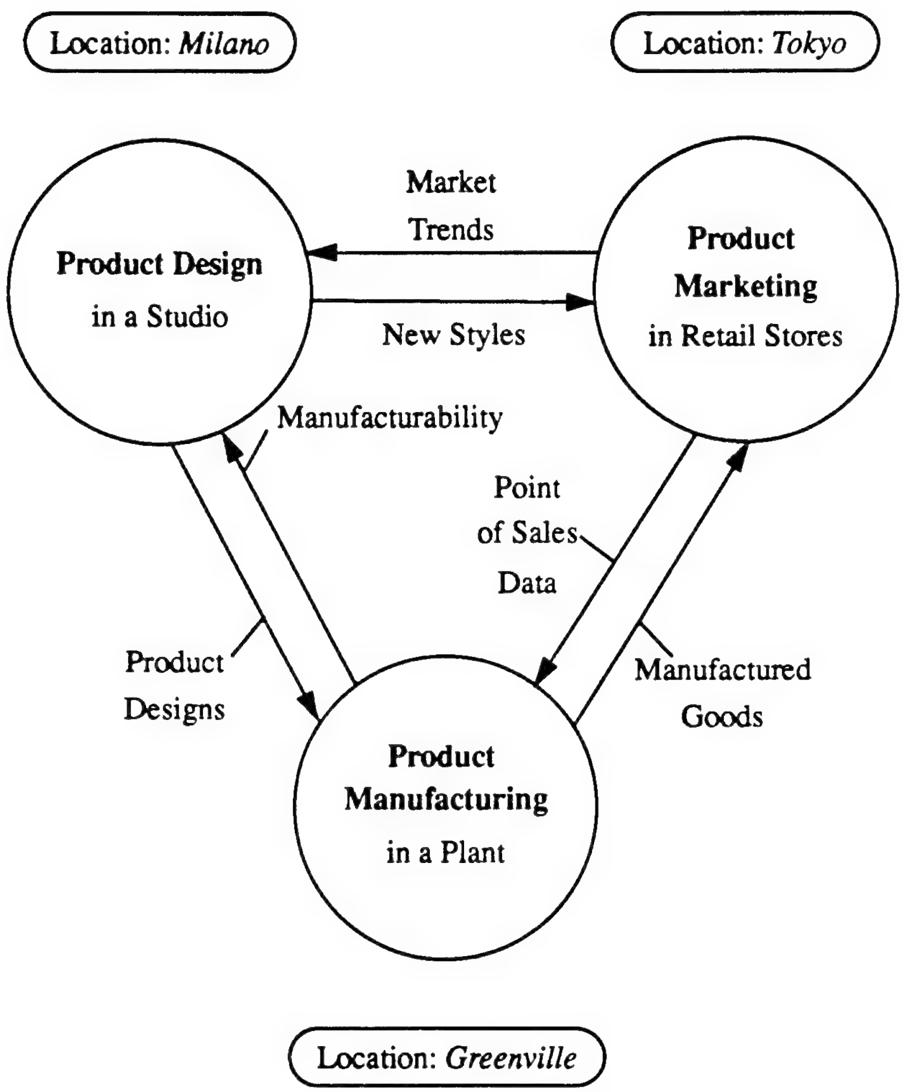

Figure 1. Primary Functions in the Textile/Apparel Complex.

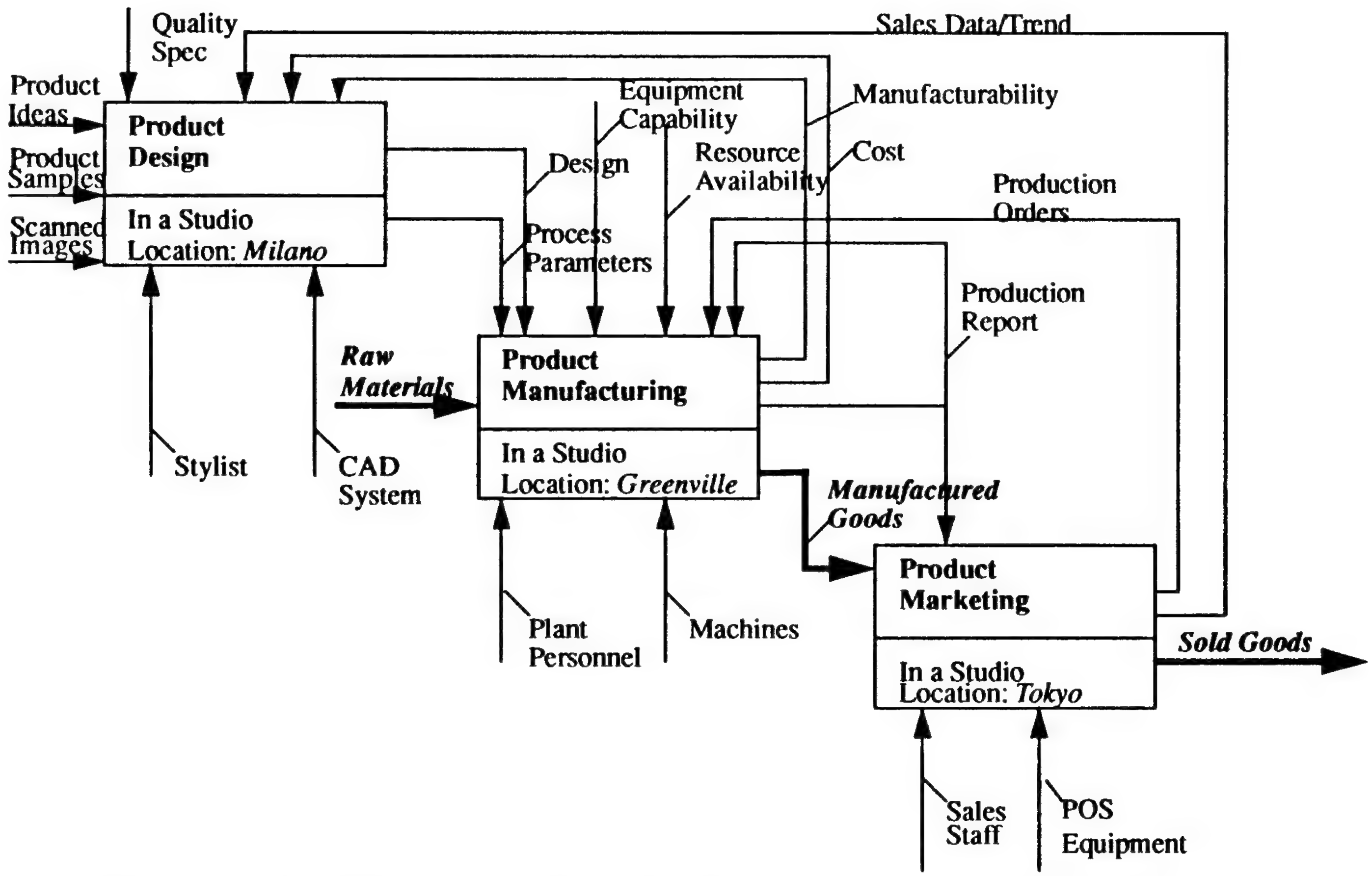

Figure 2. Detailed View of the Primary Functions in the Textile-Apparel Complex.

techniques -- will largely determine its success or failure in the global market.

However, efficient harnessing and processing of information alone, without regard to the handling of physical entities, is inadequate. What is needed is a well-balanced control and coordination of physical *and* information handling activities in an enterprise. The handling of physical entities, viz., manufacturing, is largely carried out by mechanical elements of the enterprise system (e.g., machines, robots); information entities are processed by electronic elements (e.g., computers). Thus, there is a need to effect synergy or integration between the two sets of tasks -- mechanical and electronic -- making the application of mechatronics the logical route to be adopted by the textile-apparel industrial complex. The applications of mechatronic elements in textile and apparel production systems are presently examined.

2.1 MECHATRONIC ELEMENTS IN A TEXTILE ENTERPRISE

Figure 3 shows yet another view of the principal functions in a textile manufacturing enterprise. In the *textile design* function, the designer is responsible for producing a design that meets both the aesthetic and functional demands placed by the consumer. In addition, for a design to find its way into the marketplace, the designer must consider the manufacturability of the product. In other words, design for manufacturability (DFM) and concurrent engineering (CE) principles should be followed by the designer so that the designed product can indeed be manufactured by the enterprise. For example, a fabric that calls for intricate woven patterns cannot be manufactured if the weaving machines in the plant are not equipped with Jacquard heads. Similarly, if the equipment cannot handle very fine fibers in yarn production, the proposed product will not see the light of day. Thus successful textile product design calls for a careful synthesis of the various elements of the domain, viz., material characteristics, processability, production capabilities, and consumer-driven product aesthetics and functionality. The predominant activity in textile design is information handling which is denoted by the rounded corners of the box in the figure.

2.1.1 Computer-Aided Design. Computer-Aided Design (CAD) systems, the first of the mechatronic elements, are rapidly proliferating in the textile enterprise. A typical CAD system consists of a personal computer or workstation equipped with input devices, such as an image scanner and a video camera, and output devices such as a color monitor and a color printer. With the advancements in printing technology, often it becomes difficult to visually distinguish between the design on the paper and the fabric. The CAD system can generate processing information for weaving machines, such as lifting of the harnesses, that can be directly sent to electronic dobbies and jacquards. The engineering design of woven textile structures is a complex task and makes extensive use of empirical knowledge accumulated over time. Table 1 illustrates the interrelationships between major design parameters and functional characteristics of woven structures [1]. Computer-Aided Engineering (CAE) software tools such as finite element methods, equation solvers, visualization tools and 3-D modeling help the designer balance the functional requirements of the product with the aesthetics.

The database associated with a CAD system consists of a library of designs created in the enterprise. This library typically includes color schemes, fibers, yarns, fabrics and their characteristics and performance metrics. The CAD system needs to access the database of process sequences, machines and equipment capabilities maintained in the enterprise. Another vital input source for the designer is the marketing database that captures the consumer's profile along with information on past performance of the product in the market. In other words, the

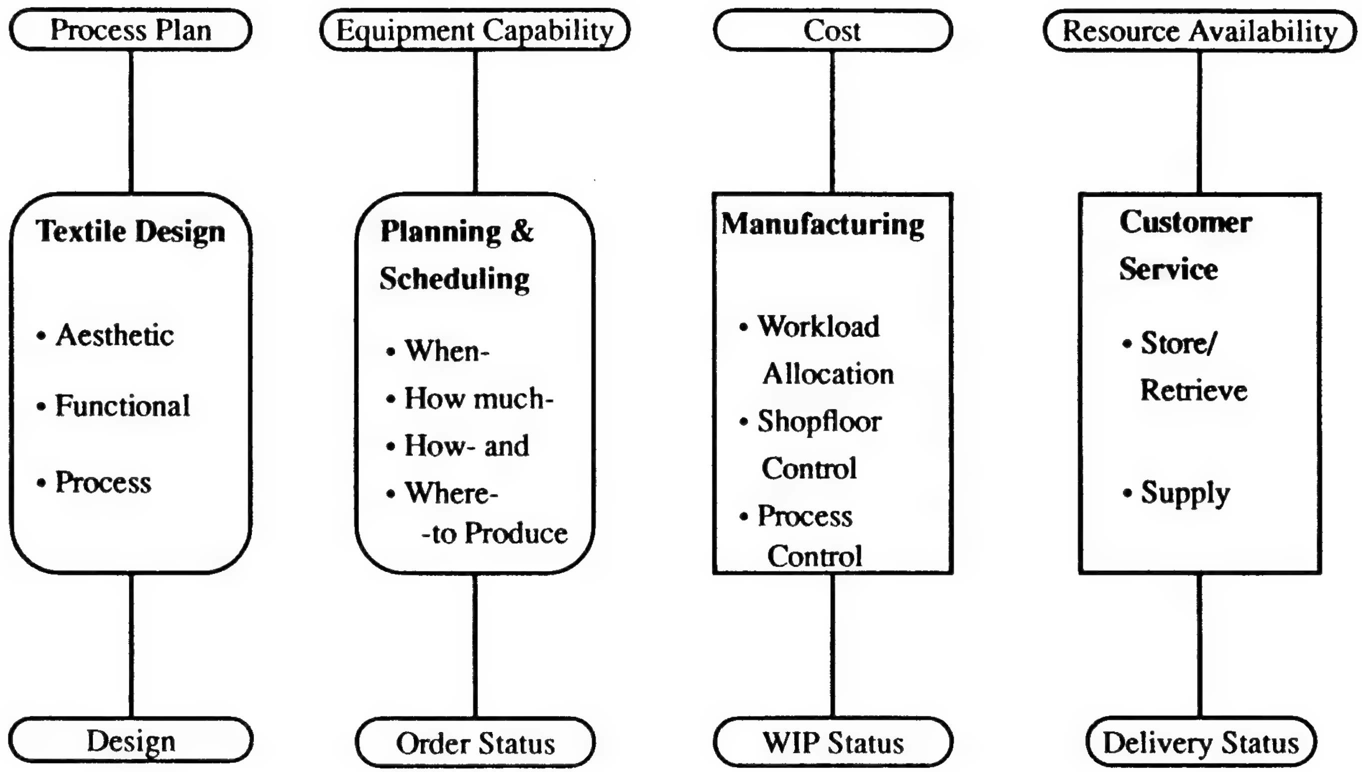

Figure 3. Distributed Databases in the Textile-Apparel Complex.

Table 1. Engineering Design of Woven Structures (from [1]).

Increase Only	Tensile Strength	Initial Modulus	Tearing Strength	Bending Stiffness	Air-Permeability	Abrasion Resistance	Shear Resistance	Flexural Endurance	Thickness
Fiber Linear Density (Cross-Sectional Area)	—	—	—	↑	↑	↑	—	↓	↑
Yarn Linear Density	↑	↑	↑	↑	↓	↑	↑	⤵	↑
Yarn Twist	⤵	↓	—	↑	↑	⤵	↑	⤵	↓
Threads/inch	⤵	↑	↓	↑	↓	↑	↑	↓	↑
Interlacings per Unit Area (Weave Pattern)	↓	↓	↓	↑	↓	↑	↑	↓	↑

CAD system should provide the designer with access to its own database in addition to those distributed in other functions of the enterprise. A key requirement therefore is electronic data interchange (EDI) between the various functions of the enterprise. Rather than have a physically centralized or single database with all the enterprise information, a distributed database with each function owning the data pertaining to that activity would be a more desirable solution for ensuring data integrity and data currency.

Advantages of CAD Systems: A CAD system provides QR capabilities to an enterprise by compressing the design-manufacturing-marketing cycle time. Designs, stored in libraries, can be recalled, modified and quickly evaluated. The number of prototypes or samples to be physically produced prior to acceptance by the customer is greatly reduced, thus resulting in cost and time savings. The enterprise can respond faster to changes in the market based on point-of-sale (POS) information generated by the marketing department. Since the CAD systems can directly download process information (e.g., machine settings, lifting plan) to the shop-floor, designs can be quickly brought to production. Moreover, since human intervention is being minimized or even eliminated, information translation errors are greatly reduced leading to a better quality product. For example, when the lifting plan is directly sent by the CAD system to the electronic dobby, operator errors in key-punching or programming can be avoided. Thus, by applying one of the principal mechatronic elements, the textile enterprise can design products to effectively respond to market needs.

2.1.2 Computer-Aided Process Planning and Scheduling. As shown in Figure 3, the *process planning and scheduling* function is the next major function in a textile enterprise. As with design, this function is essentially an information processing operation in which answers to the following important questions are determined: (i) how to produce? (ii) when to produce? (iii) what product mix to produce? (iv) how much to produce? and (v) where to produce?

In process planning, the correct set and sequence of operations required to manufacture the product are determined. In production planning and scheduling, the objective is to optimize the utilization of scarce resources while producing a quality product that meets market demands. This function becomes especially critical in the context of JIT manufacturing philosophy. In such a scenario, the apparel company expects shipment of fabric to arrive *just in time* to be spread in the cutting room. A real-world example is the existing relationship between Swift Textiles, a major denim producer in the U.S., and Levi Strauss, the leading jeans manufacturer. Even the arrangement of fabric rolls in the delivery trucks matches the order in which the fabrics will be spread and cut by the apparel manufacturer. When such fine coordination and control are necessary, planning and scheduling of production become extremely critical in the textile-apparel life-cycle. Carrying the JIT philosophy further upstream, if the fabric manufacturer is procuring yarn from outside sources, the planning and scheduling function provides the necessary information to forecast and order raw materials so that they arrive just in time to be taken to the production floor. Likewise, the planning function in a yarn manufacturing operation helps to order fibers, and the link continues further upstream in the chain. In short, as the textile-apparel complex moves towards JIT manufacturing, the planning and scheduling function in the textile enterprise assumes a pivotal role in maintaining the link. The use of the computer in this function not only simplifies the task, but also improves the quality of the results.

The information required by the planning and scheduling function includes plant equipment capabilities, available capacities, inventory levels (stock and work-in-process), order sizes and due dates. The database associated with a computer-based planning and scheduling system will

typically contain information on plant equipment capabilities and available capacities. Moreover, as with CAD systems, the planning system should be able to electronically access other databases in the enterprise (see Figure 3) containing inventory information, order information (order sizes and due dates) and process information (process sequences and times). Materials Requirement Planning and Manufacturing Resources Planning Systems (MRP, MRP II systems) are the commonly used tools for this task. A simulation tool can be effectively used to evaluate various production scenarios prior to scheduling production. Operations Research techniques and tools (e.g., Linear and Dynamic programming, PERT/CPM) can also be used for this activity in the textile enterprise.

Advantages of Computer-Aided Process Planning and Scheduling: The use of computer-based planning and scheduling tools can help to produce the right mix of goods, eliminate bottlenecks in manufacturing and reduce production times. Consequently, the cost of producing the goods can be reduced. Moreover, the organization can be geared to meet market demands and operate successfully under the JIT manufacturing philosophy.

2.1.3 Computer-Aided Manufacturing on the Shop-Floor. As shown in Figure 3, the next logical function in the textile enterprise is *manufacturing*. In this function, the raw materials are physically transformed into finished goods. For example, in a yarn manufacturing facility, fibers are opened, cleaned, carded, drawn and spun into yarn using the appropriate technology, viz., ring, rotor, air-jet or friction spinning. In the case of a woven fabric manufacturing facility, one-dimensional yarns are converted into a two-dimensional fabric through a sequence of steps, viz., winding, warping, slashing, drawing-in and weaving using the appropriate weft insertion technology. In either scenario, handling of physical entities (fiber, yarn or fabric) is the primary function; however, the processes themselves are governed by the information entities generated in the design and planning functions.

Computers are rapidly becoming an integral part of the shop-floor operations in a textile enterprise. Coupled with the proliferation of automation and robotics, a truly computer-aided manufacturing environment is emerging. In other words, the mechatronics philosophy is being applied on the shop-floor. The inroads made by mechatronics can be grouped into two major categories: process control and materials handling.

Process Control and Flexible Manufacturing: Figure 4 shows the hierarchical flow of information in a textile enterprise. The different levels of control in the plant are also shown in the figure. At Level 0, sensors mounted on different parts of the machine transmit the information that is used by the *machine* controller at Level 1. Likewise, the controllers at Level 2, regulate individual *lines* such as opening and carding, and those at Level 3 control *departments* (e.g., spinning, weaving), and so on. Thus, by adopting the *distributed process control* philosophy, the manufacturing process can be monitored and finely controlled at the desired level. For example, the quality of the card sliver is controlled by the autoleveller on the carding machine, while the computer in the weaving plant monitors all the weaving machines and provides appropriate information to the weaving room manager.

At the heart of changes taking place in process control and monitoring on the shop-floor is the expanded role of the machines themselves. The machines are no longer just processing the physical entities, but also are serving as nerve centers or nodes in information acquisition and utilization on the shop-floor. For example, in Rieter's concept of Computer-Integrated Spinning (CIS), the Spin Control Center can download yarn and machine settings directly to the machines in the spinning line. This feature -- rapid reconfiguration and increased flexibility in products produced -- would greatly facilitate quick changeovers in yarns produced in a plant operating

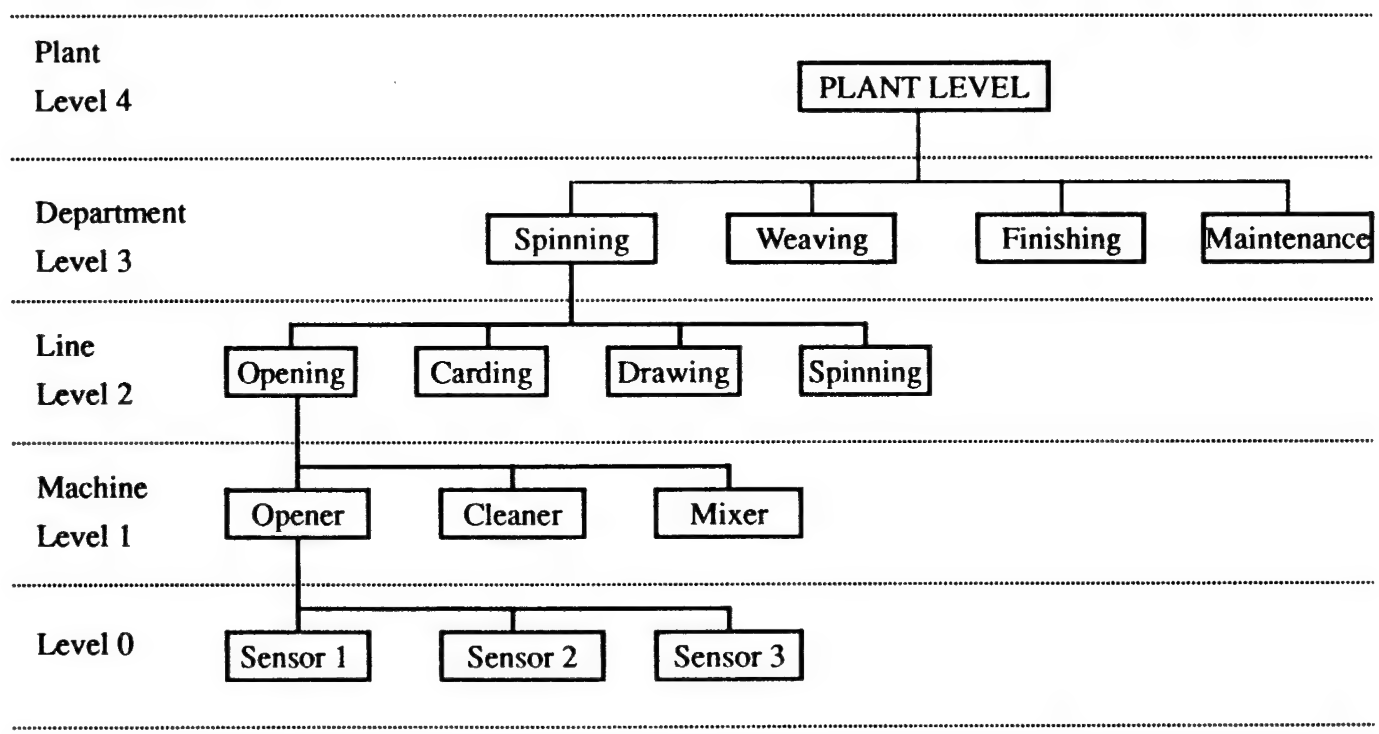

Figure 4. Information Flow and Control in a Textile Enterprise.

in a QR mode. Likewise, Murata, the Japanese textile machinery manufacturer, is a leader in the real-world application of mechatronics to yarn manufacturing [15].

Today's weaving machines are equipped with features such as on-board intelligence, touch screen and graphic displays, and bi-directional communication capability. As the fabric pattern or fabric sett changes, the appropriate pattern data and machine settings can be directly downloaded from the computer to the machine. Maintenance and trouble-shooting instructions can also be displayed by the operator on the machine. Machine performance parameters (e.g., running time, picks inserted, types of stops, downtime and efficiency) are gathered by the machine and sent to the department-wide monitoring and control computer. Thus the weaving machine is an excellent example of the synergy characteristic of a mechatronic production system: it produces a physical entity, viz., fabric, while effectively processing vital information in the plant.

In short, process control in a textile enterprise -- which requires the integration of mechanical and electronic elements of the manufacturing system -- is no longer bound by its traditional definition of making corrections to an out-of-control process. Instead, its scope has been expanded to include customization of the process to provide the necessary flexibility associated with small lot production sizes coupled with frequent changes and shorter lead times for products. A flexible manufacturing system (FMS), or a textile version of it, is slowly emerging.

Materials Handling and Process Linkages: Materials Handling (MH) can be defined as the use of the *right* method or technique to ensure the availability of the *right* material in the *right* form in the *right* amount at the *right* place and at the *right* cost [8]. This definition clearly shows the importance of proper materials handling for attaining the enterprise objective and the five Rs, especially in the context of QR and JIT manufacturing. While MH is typically associated with the movement and handling of physical entities in the plant, a crucial element in the proper functioning of the system is the associated information. If the material on the shop-floor is misdirected due to information errors, bottlenecks might occur. More importantly, consumer demands cannot be met on time resulting in economic and business consequences for the enterprise. Thus there is a need for the application of mechatronics to the domain of MH in the textile enterprise.

In addition to the use of Automated Guided Vehicles (AGV) and Automated Storage and Retrieval Systems (AS/RS) for materials handling, the current trend in textile manufacturing is towards process linkages, i.e., automatically routing material from one processing machine to the next without human intervention. One of the first, going back several decades, was transportation of opened and cleaned fibers directly from the last machine in the opening room to the cards using chutes. However, this linkage or process integration has gone further. The roving bobbins are transported on an overhead rail directly to the ring frame. The bobbins from the ring frame are directly transported to the winding machine; an example of such a system is Murata's Mach Coner. Such systems can also handle several different types of yarns providing a greater product flexibility to the plant. Robotic arms doff the cones from the winding machines and transport them to an inspection station. A vision system inspects the package for defects and good quality cones are transported to be packaged, palletized and rendered ready for shipping. This type of process integration not only minimizes human handling of material (consequently, fewer opportunities for mishandling, yarn mix-ups and soiling) but also greatly reduces the processing time in the plant, a factor that becomes critical in a QR operating environment.

Moving further downstream in the textile process, winding and warping operations are being linked. The cones from the winder are directly transported to the warping machine on an

overhead rail. At the warper, a warper creel robot automatically supplies the package to the creel. The fabric on the weaving machine is automatically doffed and transported to the inspection station. At ITMA '91, ELBIT Vision Systems of Israel demonstrated a vision-based fabric inspection system [15]. The fabric is scanned by eight videocameras at 100 m/min. Initially, the system, working on greige goods only, "learns" the fabric pattern on a 3" x 3" sample. The observed defects are classified into spot, vertical, horizontal and area defects. This system is another illustration of how information processing in textile operations has been greatly aided by the rapid advancements in computing technology.

In short, process integration, robotics and vision-based systems used in the textile enterprise illustrate the synergistic functioning of the mechanical and electronic elements in the system.

Advantages of CAM on the Shop-Floor: By utilizing appropriate technologies, including the computer, to effectively integrate the mechanical and electronic systems on the shop-floor, the textile enterprise is better positioned to produce a quality product that meets the requirements of the consumer. For an enterprise operating in a QR mode under the JIT philosophy, CAM on the shop-floor becomes even more critical. In fact, CAM along with EDI are often the prerequisites for achieving such an environment.

2.2 MECHATRONIC ELEMENTS IN AN APPAREL ENTERPRISE

The major functions shown in Figure 3 are also applicable to an apparel manufacturing enterprise. In the interest of brevity, only issues that are unique to the apparel sector and not found in textile manufacturing will be discussed here.

2.2.1 Computer-Aided Design and Marker Making. CAD systems used in apparel design have features similar to those used in textile design. In addition, the systems allow the designer to graphically simulate the drape and appearance of the garment on 3-D forms. Attempts are being made to integrate data on fabric characteristics from the Kawabata Hand Evaluation System (KES) with the design software. This type of link will help the designer better visualize how the garment being designed will drape on the human form.

CAD systems are also used for grading and marker making. In grading, the garment's base pattern parts are used to generate the pattern parts for the various sizes in that specific style. Grading rules are built into the software. The *marker* specifies the desired layout of the garment's pattern parts on the fabric to be cut. The purpose of the marker making process is to pack the pattern parts so that fabric utilization is maximized. Since fabric accounts for a significant proportion of the garment cost, it is important to maximize fabric utilization. Heuristics are being built into the software to achieve this objective. The CAD system also generates the path coordinates for the NC fabric cutting machine; this data is then directly transmitted to the NC cutter thus creating a true CAD-CAM link.

2.2.2 Computer-Aided Process Planning and Scheduling. A unique issue in the apparel industry is the large number of operations involved in making a garment. Also, the operation times, required machine features and operator skills vary with the operation. Therefore, process planning is a complex task requiring the use of computers. Moreover, the process planner needs to access the various databases in the enterprise and also draw upon experiential knowledge. Further downstream, the production planning and scheduling process is complicated by the number of sizes, size distributions and colors associated with a single garment style. Software systems known as *cut order planning* software incorporate optimization algorithms;

these packages enable manufacturers to better control their manufacturing costs and be competitive in the marketplace.

2.2.3 Computer-Aided Manufacturing. Analogous to the weaving machines in a textile plant, sewing machines are being equipped with data terminals that are connected to a monitoring and control system on the shop-floor. Machine settings can be downloaded from the central computer. In an experimental system exhibited at the 1990 Bobbin Show, a Juki sewing machine was using fabric property information based on the KES system to adjust its sewing parameters. This is an excellent application of mechatronics: Fabric-related information is used to change the mechanical processing of the part on the sewing machine so that a defect-free garment can be produced. The ability to rapidly reconfigure the sewing parameters -- based on fabric properties -- will enable a plant to quickly respond to changes in fabric and garment styles. The MITI program in Japan and the Singer company have focused on automating the garment assembly operation, i.e., automatically moving the parts from one operation to the other using mechanical robot arms. However, they have not yet become commercially viable.

2.2.4 Materials Handling. In the area of materials handling, viz., the movement of garment parts in the apparel enterprise, studies have shown that MH and related tasks occupy 60% of the operator's time, whereas the actual sewing accounts for only 20% of the operator's time [28]. Thus, reducing the MH time could greatly contribute to increasing the productivity and profitability of the organization. A MH system known as the *unit production system* (UPS) is making inroads into the apparel industry. The underlying philosophy of the UPS is the processing of a garment in a lot or bundle size of one, as opposed to 36 or 72 units in the more commonly used *bundle system* in the industry. Consequently, the UPS is ideal for producing smaller lot sizes requiring quick turnaround with minimum work-in-process (WIP) inventory levels. In the UPS, an overhead conveyor moves hangers between the workstations; each hanger contains the parts for a single garment. At each workstation, the relevant sewing operation is performed on the parts which typically don't have to be removed from the hanger for sewing. The bar-coded hangers are automatically routed by the control system to the sewing station for the next operation; consequently, the WIP levels can be continuously tracked by the UPS. Thus the UPS is another good example of the application of the principles of mechatronics: Mechanical elements guide the hangers to the appropriate station based on the operation to be performed, availability and skill level of operator, and machine availability and capability.

Having discussed the role of mechatronics separately in textile and apparel operations, issues at the textile-apparel-retail interface are presently examined.

2.3 MECHATRONIC ELEMENTS AT THE TEXTILE-APPAREL-RETAIL INTERFACE

A critical element in achieving a truly integrated textile-apparel complex is the link between the various components, viz., the textile manufacturer, apparel producer and the retailer. Essentially, at each interface, there is the movement of goods (physical entities) controlled by the associated information. Consequently, there is a need to apply mechatronics to ensure a seamless transfer of goods and information.

2.3.1 Role and Importance of Point-of-Sale Data. The POS data gathered in the retail store is transmitted electronically by each store to its headquarters. In turn, the collated information is

used by the company to place orders with apparel suppliers. This information is also used by the apparel producers to track the performance of goods in the market and to forecast production. The POS data plays a critical role in a QR operating environment where the apparel producer needs to quickly alter production practices to respond to the market. An excellent case study in the effective use of POS data is the GAP retail chain in the United States. GAP tracks product performance on a continuing basis and typically has a complete turnover of inventory in approximately two weeks.

The apparel manufacturer uses the POS data (furnished by the retailer) and past history to forecast fabric requirements. Orders are placed with the fabric manufacturer as late in the production-retailing cycle as possible so that the quantity ordered closely matches the anticipated consumption. Moreover, the fabric and other materials must arrive in time to be cut and sewn, thus necessitating a JIT environment at the textile supplier.

2.3.2 The Quality Chain. The burden of maintaining quality is being gradually shifted to the supplier. Thus, when a roll of cloth is shipped to the apparel manufacturer, it typically carries a defect map (location and extent of defects) along with other fabric-related information. The defects marked at the fabric inspection stage in the textile plant can be detected by sensors on the spreading machine and appropriate action taken. Further upstream, similar linkages need to exist between yarn and fabric producers, and fiber and yarn producers, respectively. Since information plays a critical role at each interface, the proper transfer and processing of information are of utmost importance in the textile-apparel complex.

In summary, the principles of mechatronics are being applied in all facets of textile-apparel production systems ranging from design to marketing, thus laying the ground for realizing CDDAM. Moreover, the underlying theme behind mechatronics is to bring about true integration between the various functions of an enterprise by tearing down the *walls* separating them; this is slowly, but surely, becoming a reality in the textile-apparel complex. Major tools necessary for successfully applying mechatronics in the textile/apparel industry are presently discussed.

3. Mechatronics, Information Engineering and Knowledge Processing

The successful application of mechatronics in the textile-apparel complex implies the effective control of physical and information entities in the enterprise. Two broad classes of tools and techniques are needed for this purpose: one dealing primarily with physical entities and the other with information entities. Note, however, that this classification only facilitates the discussion and does not diminish the need for -- and importance of -- the two sets of tools working together seamlessly. The focus here is on the tools for information and knowledge processing.

3.1 INFORMATION ENGINEERING AND THE TEXTILE-APPAREL COMPLEX

Having the right information, in the right format, at the right place and at the right time is critical to realizing the five Rs of the enterprise: to produce the *right* product, of the *right* quality, in the *right* quantity, at the *right* price and at the *right* time. Information engineering -- the process of identifying, analyzing, synthesizing and structuring information entities and their flows -- is a powerful means or tool to help an organization effectively utilize its

enterprise-wide information resources. In fact, information engineering is the first step toward the successful implementation of CIM systems in an enterprise.

3.2 ENTERPRISE ARCHITECTURE AND STRUCTURED ANALYSIS AND DESIGN TOOLS

As with any engineering activity, the result of applying information engineering concepts is a detailed knowledge and understanding of the functions and information associated with the enterprise. For example, it is important for the product design function to have timely access to various pieces of information such as product functionality and equipment capability (see also Figure 3). The first step in setting up an information system for design activity is a detailed analysis of the function and its associated information entities. A systematic function-by-function modeling of the enterprise activities results in a definition of the enterprise known as the *enterprise architecture*. However, to develop such an architecture or model of an enterprise, modeling methodologies and tools are necessary. Such tools are also known as structured analysis and design tools or SADT. Several diagramming and flowcharting techniques have been proposed in literature [20]. For modeling manufacturing systems, the important methodologies are the IDEF methodology from the U.S. Air Force [29], the ESPRIT CIM-OSA [16] and Zachman's Information Systems Architecture [32]. The relative merits and shortcomings of the three systems have been discussed in [19, 27].

3.2.1 Electronic Data Interchange. Figure 5 shows the flow of information between the major building blocks of the fiber-textile-apparel complex; it also illustrates the interdependency and tight linkages between the components. For example, POS data will eventually (through the retailer - apparel manufacturer - fabric manufacturer - yarn manufacturer path) influence the type and quantity of fibers bought by the yarn manufacturer. For the information to be of value, it must be transmitted quickly and accurately. An effective medium is electronic transfer, commonly referred to as electronic data interchange or EDI. Such electronic transfer is both essential and critical, especially if the textile-apparel complex is to operate in a QR or JIT environment (e.g., the relationship between Swift Textiles and Levi Strauss).

EDI is commonly defined as the computer-to-computer exchange of business documents between organizations in a standard electronic format. Even within an organization, EDI between the functional units (see Figure 2) helps streamline processes that are critical for efficient operation. EDI eliminates the paper shuffle and enables an organization to satisfy its customer's needs by providing instantaneous information on both orders and quality problems (including trouble-shooting).

As with any chain, the textile-apparel-retail chain is as strong only as its weakest link. Thus, if the information flow between the fabric manufacturer and the auxiliaries supplier in Figure 5 breaks down, the short-term impact will be felt by the apparel manufacturer; however, in the long-term, all the nodes in the chain will be affected. As organizations increasingly rely on EDI, data security and correct interpretation of data, viz., what is perceived is what was meant, become critical. Inasmuch as EDI is efficient, powerful and fast, a recent incident in the New

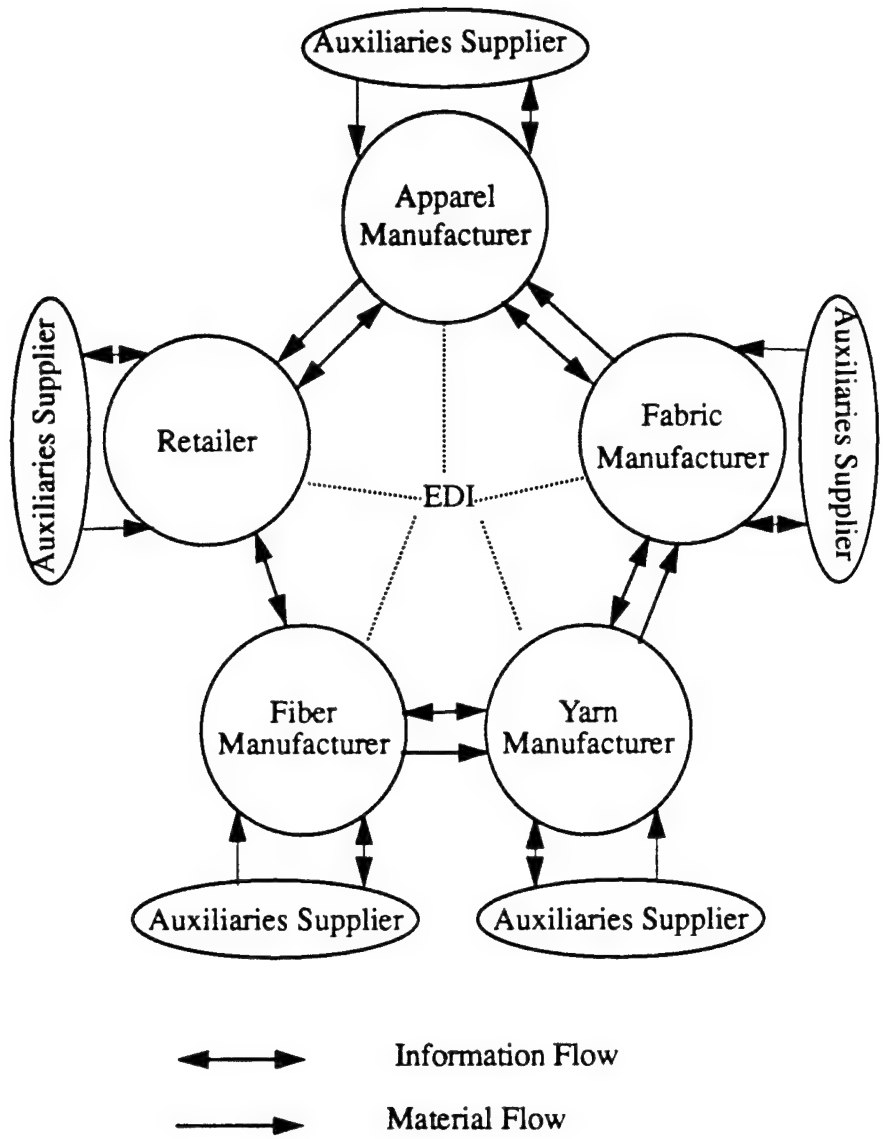

Figure 5. EDI in the Textile-Apparel Complex.

York Stock Exchange[1] illustrates the vulnerability of EDI and underscores the need for proper safeguards and security standards.

3.2.2 Information Exchange Standards. The textile-apparel complex deals with different types of data in the product's life-cycle, viz., design, manufacturing, performance, quality, testing and marketing. As shown in Figures 3 and 5, such a CIM database for the enterprise is likely to be physically distributed across the various functions of the enterprise. The databases may be on different hardware platforms; each function may store and access the data in a certain format; the same data may be *interpreted* or used differently by another function. Some of these systems may be full-fledged database management systems, while others might only permit file transfer. Therefore, for implementing EDI within an enterprise and across companies, some common rules or *standards* for representing and exchanging information are required.

For example, the internal representation of pattern data in the marker making system depends on the system developer. For example, the data format in the Gerber system is different from that of the system marketed by Microdynamics. If an apparel manufacturer has a different system at each of its multi-plant operations, pattern data cannot be directly exchanged electronically, thus precluding true EDI. A similar problem (of larger magnitude) is faced by the U.S. Department of Defense (DoD). DoD is typically forced into issuing *hard* patterns at bid solicitations for apparel procurement. If a common data format were adopted, the industry could implement EDI and derive its benefits: (i) No information will be lost when data is interchanged between systems; and (ii) No complex and expensive coding and decoding protocols will be required at the sending and receiving systems, respectively.

Standards for Product Life-Cycle: A long-term approach to developing such standards is to examine the total life-cycle data of the textile/apparel product. An international initiative, known as PDES, Product Data Exchange using STEP, will facilitate the exchange of a complete product data model with sufficient information as to be interpretable by advanced CAD/CAM systems without human intervention. These concepts are currently being investigated by the hardgoods industry, viz., mechanical parts, mechanical assemblies and electrical printed wiring board products [23]. STEP (*ST*andard for *E*xchange of *P*roduct Model data) is an international standard (defined by International Standards Organization) to represent product data in a neutral format that can be used throughout the life-cycle of the product. Both these initiatives are slowly making their way into the softgoods or textile/apparel world [17]. The information architecture of the enterprise provides the necessary foundation for developing such standards necessary for the design and implementation of an integrated enterprise information system.

DoD Computer-Aided Acquisition and Logistic Support (CALS): CALS is a DoD and Industry initiate to enable and accelerate the integration and use of digital technical information for weapon system acquisition, design, manufacture and support. The CALS program facilitates the transition from paper-intensive processes to a highly automated and integrated mode of operation, thereby improving productivity and quality of acquisition and logistic support

[1]On March 25, 1992, an order to sell $10 Million worth of shares on the New York Stock Exchange, was misinterpreted and processed by the data entry clerk at Salomon Brothers -- a brokerage firm -- as an order to sell 10 million shares; this error caused the stock market to drop sharply during the closing minutes of the day. The large sell-off was quickly traced to the source and immediate steps were taken to minimize the consequences.

processes [3]. Among the associated benefits of this initiative are: (i) Reduced acquisition and support costs through elimination of duplicative, manual and error prone processes; (ii) Improved responsiveness of the industrial base by development of integrated design and manufacturing capabilities and by Industry networking and communication among manufacturers based on digital product descriptions; and (iii) Improved quality and timeliness of technical information for support planning, reprocurement, training and maintenance, as well as improved reliability and maintainability of weapon system designs through direct coupling to CAD/CAE processes and databases.

Based on the objectives of the CALS program and its related benefits, the CALS strategy could very well be adopted by the textile/apparel industry to be responsive to the needs of the consumer by delivering a quality product in a timely manner while reducing the manufacturing and distribution costs.

3.2.3 Information Exchange and Communication Networks. A prerequisite for effective information sharing is a well designed and implemented communication network (collection of hardware and software) within the building blocks of the textile-apparel complex and between them. For example, the CAD system can access the equipment capability database over a local area network (LAN) if the two databases are maintained within the same physical facility. Otherwise, wide area networks or communication through modems are the means to achieve this information sharing. Likewise, weaving machines in the weave room can be nodes on a LAN with the central computer keeping track of production information, machine settings and patterns. In such a system, the settings from a weaving machine operating at high efficiencies can be electronically transferred to other machines on the shop-floor. Such electronic transfer of settings was demonstrated by Picanol at ITMA '91.

Various communication protocols have been established for information exchange [30]. The Open Systems Interconnection (OSI) Reference Model provides a generic seven-layer framework for the development of standardized communication systems from the physical layer to the application layer. The Manufacturing Automation Protocol (MAP) is based on the OSI Reference model and is extensively used in the manufacturing sector (e.g., automobiles). TOP (technical and office protocol) is a set of standard protocols used to provide a functional network for distributed information processing in technical and office environments.

The ISDN (integrated services digital networks) architecture supports the simultaneous transmission of data, video and audio. This technology opens up some exciting avenues for information sharing in the textile-apparel complex. For example, concurrent design and engineering can be practised more effectively: product designers, consumers and manufacturing personnel located in different cities can work as a team to design a product and improve its chances of success in the market. Likewise, the technology can be used to develop multimedia systems to train operators in plants, provide shop-floor trouble shooting instructions and develop product presentations for marketing.

In summary, advancements in information technology can be applied to design and implement newer ways to present, utilize and share information in the textile/apparel complex.

3.3 KNOWLEDGE PROCESSING AND THE TEXTILE-APPAREL COMPLEX

Information, a meaningful representation of data, is important to an enterprise. Equally critical, if not more valuable for an enterprise to meet its objectives, is *knowledge*, the ability to effectively utilize information. Experience and expertise acquired over time in an organization -

- be they in product design, production planning, shop-floor control or sales forecasting -- need to be captured, preserved and disseminated throughout the enterprise. The role of artificial intelligence in providing tools for this purpose are presently discussed.

3.3.1 Artificial Intelligence and Knowledge-Based Systems. Artificial Intelligence (AI) has been defined as the part of computer science concerned with designing intelligent computer systems, that is, systems that exhibit characteristics associated with intelligence in human behavior -- understanding, language, learning, reasoning and problem-solving [2]. Early research in AI was aimed at developing domain-independent reasoning systems such as the General Problem Solver (GPS). GPS could prove theorems and solve a wide variety of problems, but proved to be inadequate for larger real-world problems. Subsequently, research efforts were directed at developing efficient schemes for representing domain-specific knowledge, and the term *knowledge engineering* was born along with the concept of a knowledge-based system [5].

Knowledge-Based Systems: A knowledge-based system (KBS), commonly referred to as an *expert system*, is a software system that solves complex problems in a specific domain that would otherwise require extensive human expertise. Waterman [31] provides a basic introduction to the field of KBS from a practitioner's standpoint, while Hayes-Roth *et al.* [6] is a good reference text for system developers.

A KBS essentially consists of three major components: At the heart of the system is the *Knowledge Base* which is the repository of domain-specific knowledge. This knowledge comes from the domain expert and other sources such as domain literature. The domain knowledge is stored in the form of facts and heuristics. The *Inference Engine* contains the problem-solving strategies and applies the knowledge to the solution of actual problems based on the specific data currently in the *Working Memory*. The two major inference paradigms or solution strategies are *forward chaining* and *backward chaining*. The user of the KBS interacts with the system through the *User Interface*.

The various steps in the KBS Development Life-Cycle, viz., planning and domain selection, knowledge acquisition, knowledge representation, system testing and system deployment are discussed in [12]. The applications of KBS in various facets of the nonwoven industry, viz., product design, production planning and scheduling, shop-floor control and marketing have also been discussed in [12].

Fuzzy Logic Systems: Fuzzy logic is a discipline that lets the computer deal with shades of grey. Rather than make decisions based on just one input, several variables are integrated over time to ensure better control over the process being monitored and regulated. This technology embodies the principles of mechatronics, viz., to effectively integrate the mechanical and information components of a system. It is being extensively used in the design of elevators, information retrieval systems and stock trading programs. The technology has the potential to be applied in the textile/apparel industry for the development of better process control systems.

In summary, the design and development of information and knowledge management systems are essential for applying mechatronics successfully in the textile-apparel complex. Figure 6 attempts to pictorially represent an integrated view of the relationship between the enterprise functions and the relevant data elements. Central to accomplishing such an integrated environment are the various information and knowledge processing technologies discussed in this section. Some specific research endeavors involving the application of these tools to textile-apparel production systems are presently discussed.

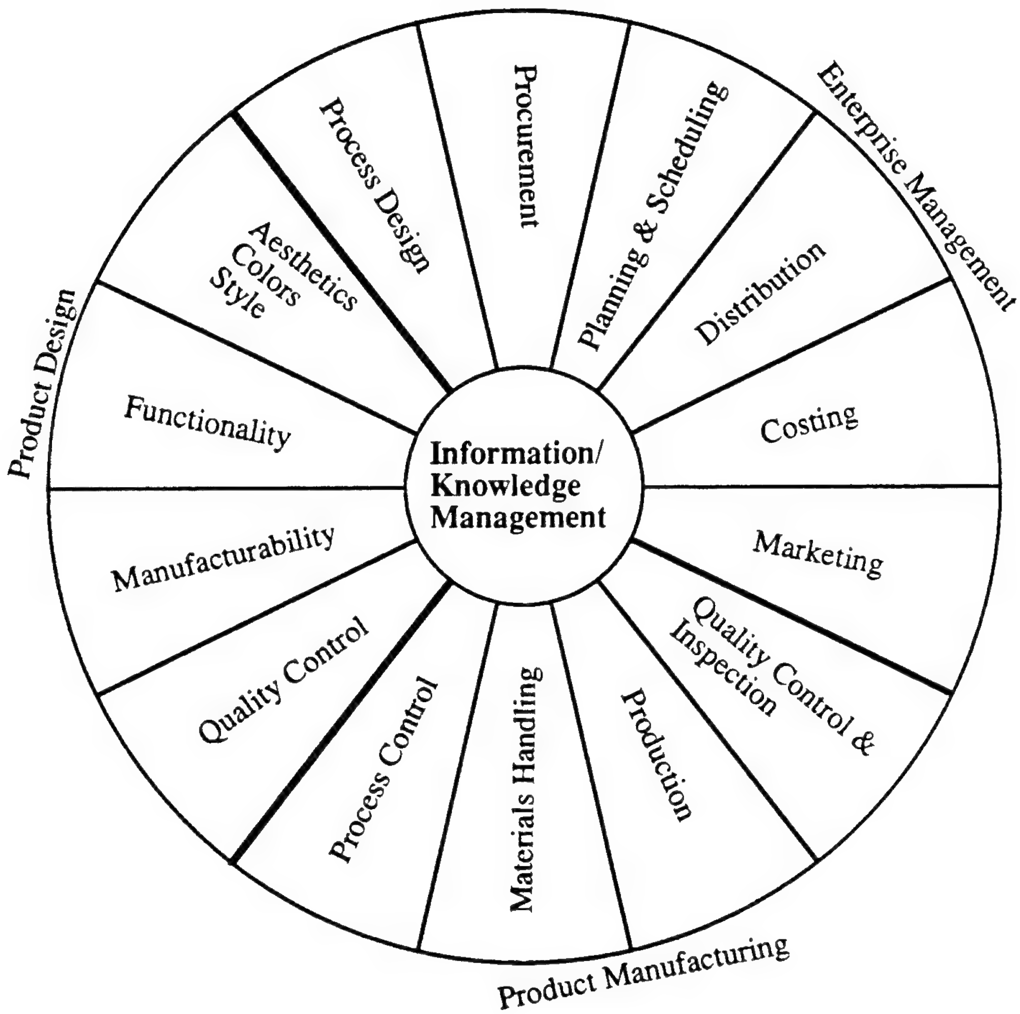

Figure 6. Information and Knowledge Management in the Textile-Apparel Complex.

4. Research in Textile/Apparel Mechatronics

Around the world, there are several research endeavors aimed at applying the principles of mechatronics to the textile-apparel complex. In this section, the focus is on a few major initiatives in the area of information and knowledge processing.

4.1 MANUFACTURING ENTERPRISE ARCHITECTURE

The manufacturing enterprise architecture (MEA) is proposed as the framework that captures, represents and integrates the three major facets of an enterprise, viz., function, information and dynamics [7]. The ultimate objective of MEA research is to design and develop an integrated modeling methodology and software framework that can be used for modeling and effectively running a manufacturing enterprise. Once the modeling software framework is developed, the need for appropriate software tools or *agents* for carrying out each of the functions in the enterprise will be identified; the available tools will then be integrated into the framework. Otherwise, such tools will be developed leading to the creation of a single integrated software environment. Currently, research is aimed at developing a modeling methodology and software modeling tools necessary for the development of an enterprise architecture.

Need for MEA: The architecture, developed by adopting a systems approach to manufacturing, can serve as a blueprint for the effective implementation of new technologies, including computers, which are central to the successful operation of the enterprise. The architecture can be used as a communication vehicle in an enterprise both during the analysis of the enterprise operations and subsequently during the implementation of changes resulting from the analysis. The architecture can also provide the necessary foundation to develop specifications and standards for the seamless integration of the various islands of automation in an enterprise [7].

Structure of MEA: MEA consists of three models, viz., the entity model, the activity model and a model to represent knowledge and beliefs about a manufacturing enterprise [26]. The entity model is a representation of the enterprise entities and their relationships. The activity model is a representation of the various functions performed in operating the enterprise. The object-oriented framework is being designed to overcome one of the major shortcomings of the IDEF methodology identified during earlier research on developing an architecture for an apparel enterprise: the lack of seamless integration between the function (activity) and information (entity) models [7, 27]. Two of the major long-term objectives are to integrate enterprise dynamics with the activity and entity models, and to generate executable models.

4.1.1 Apparel Manufacturing Architecture. Under a DoD-sponsored research effort, the architecture for an apparel manufacturing enterprise has been developed. This architecture is an example of a domain-specific MEA. Based on a set of evaluation criteria developed for the selection of the modeling methodology, the US Air Force's IDEF methodology was selected and used in the development [10]. The architecture is based on extensive modeling and analysis of the operations of a major apparel manufacturing enterprise and subsequent participation of other apparel companies.

The apparel manufacturing architecture (AMA) is a comprehensive set of specifications for a computer-integrated apparel enterprise [11, 18]. AMA consists of a set of models the core of which is the *information* model which defines the schema of the shared information base for an apparel enterprise. The *function* model component of the architecture specifies how the activities carried out in an apparel manufacturing enterprise interact with each other through the

shared information base. The third component of AMA, the *dynamics* model, describes how the interactions among the enterprise activities take place over time. AMA encompasses activities spanning product development to distribution of finished goods. The activities at each level have been decomposed to the desired level of detail so that issues related to automating or computerizing the process can be investigated. Thus an architecture encompassing the textile-apparel complex can serve as a blueprint for implementing CIM in the textile/apparel industry.

4.2 KNOWLEDGE-BASED SYSTEMS FOR DEFECTS ANALYSIS

Defects in textile products significantly impact the profitability and image of the textile/apparel industry. As the consumer becomes increasingly quality conscious, better tools must be developed to effectively control defects and improve product quality. KBS technology can be applied to develop computer-assisted tools for use in the textile-apparel complex.

4.2.1 Fabric Defects Analysis System (FDAS). Research has been conducted to investigate the use of KBS technology for analyzing defects in textile and apparel manufacturing. Two systems have been developed, one for fabric defects and another for apparel defects. FDAS is a KBS for analyzing and diagnosing defects in woven textile structures. Based on information furnished by the user, FDAS identifies the defect in the fabric and the causes of the defect, and suggests suitable remedies to avoid defects. FDAS is intended for use on the shop-floor of the textile plant [24].

Figure 7 shows the framework of FDAS for the classification of defects [25]. The defect is essentially characterized by its *type* (point, line or area), *direction*, *lengthwise pattern* and *widthwise pattern*. The primary advantage of this novel classification scheme is that it is based only on the visually observable attributes of defects and, unlike traditional schemes, does not require prior knowledge of the defect. Consequently, the scheme can be used as an underlying framework for an automatic (vision-based) fabric inspection system. In addition to being a tool for analyzing defects, FDAS can be used as a valuable training tool for new fabric inspectors. FDAS has been implemented in Nexpert Object, an expert system shell, and runs under both Unix and MS-DOS environments. FDAS is linked to Oracle, the relational database management system, to record defects and to generate quality reports in the enterprise [14].

4.2.2 Sewing Defects Analysis System. SDAS (sewing defects analysis system) is a KBS for the identification and diagnosis of defects encountered in the manufacture of utility denim trousers [14]. The classification of defects is centered around the location of the defect and the nature of the defect; these are the two visual cues an inspector derives during garment inspection. An object-oriented class hierarchy has been used to represent the classification framework of SDAS. Like FDAS, SDAS is implemented in Nexpert Object and is also linked to Oracle.

4.3 KNOWLEDGE-BASED SYSTEM FOR CONTRACTOR EVALUATION

One of the major functions in the textile-apparel complex is selection of vendors for the supply of products, viz., fibers, yarns, chemicals, fabrics, buttons, zippers, or apparel. Since there are multiple sources for each of these products, the buying organization solicits bids and eventually awards a contract based on several criteria. However, the process of selecting the bidder that is most likely to deliver the best value (i.e., the required quantity, at the right time and of the

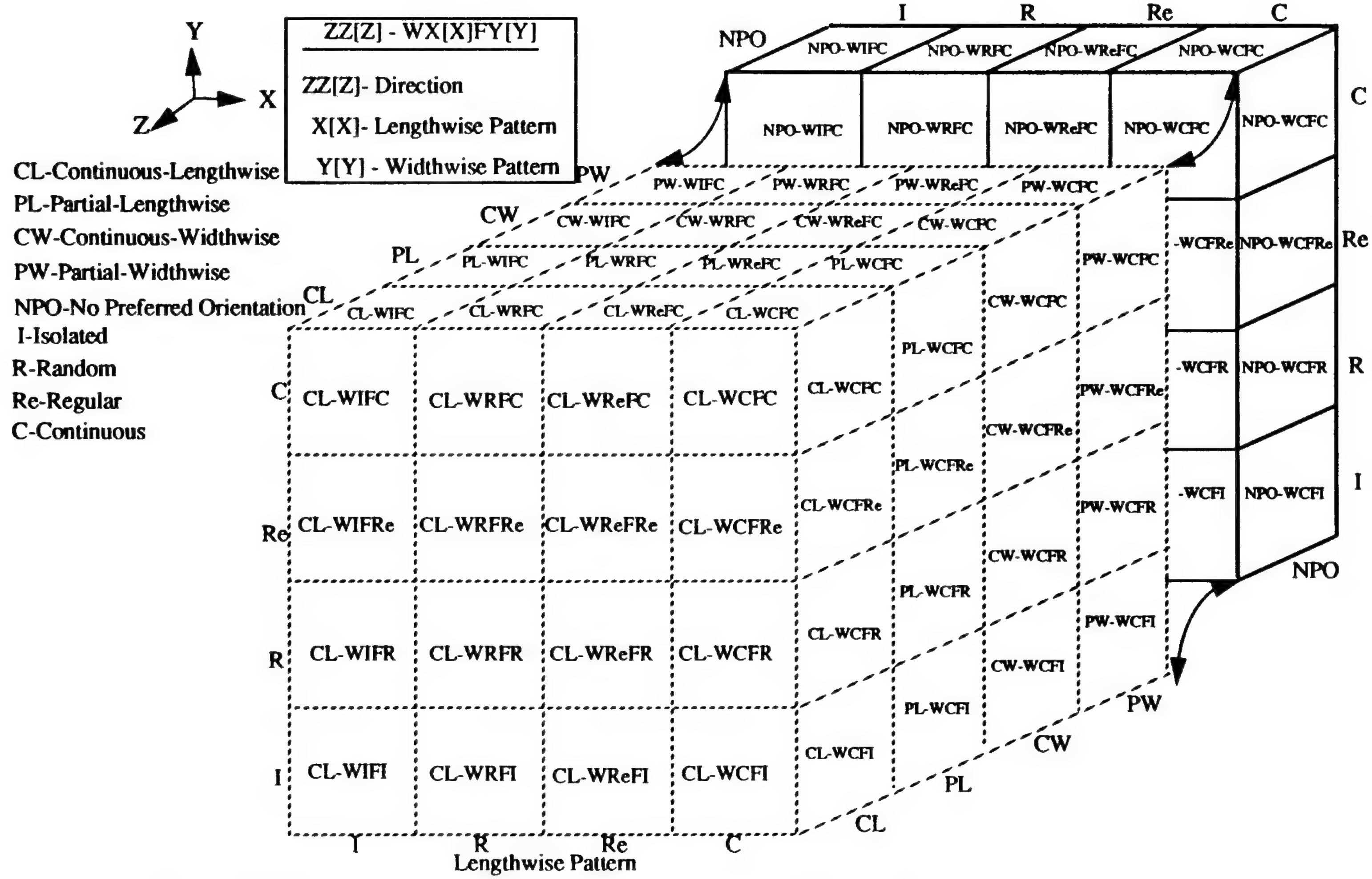

Figure 7. Classification of Fabric Defects According to Key Characteristics.

specified quality) is complex and involves extensive human judgement and experience. If an appropriate tool can be developed to carry out this task, the vendor selection process can be computerized, thus freeing the human to make creative decisions.

4.3.1 Bid Evaluation Software Tool (BEST). DoD is the single largest consumer of apparel items in the western world procuring approximately $1 billion worth of apparel every year [4]. The ultimate objective of the procurement process is to ensure the greatest value for DoD, i.e., all other conditions being met, the total cost is the lowest. With this underlying objective, research has been carried out to develop a knowledge-based decision support system for use by contracting officers at DoD to assist them in their evaluation tasks.

An Apparel Enterprise Evaluation Framework (AEEF) has been designed and developed using the KBS development methodology. In the resulting tool (BEST), the overall capability of the bidder to perform on a contract is determined based on the quality, production and financial capabilities of the bidder (see Figure 8). An object-oriented representation scheme has been used to represent AEEF. As shown in Figure 9, these top level classes are further decomposed until the value for the lowest level object can be directly obtained from the bidder [22]. AEEF is implemented in Nexpert Object and runs under both MS-DOS and Unix operating systems. To obtain the necessary information for evaluating a contractor, a set of forms known as BESTForms has been created. BESTProcess, the problem-solving engine in BEST, utilizes the data in BESTForms and comes up with a rank (on a 0-4 scale) for the bidder.

4.3.2 BEST and EDI. BESTForms represents a modest step in paving the way for EDI between DoD and its apparel suppliers [13]. Bidders can submit the necessary information on disks that can be loaded at DoD and used with BEST. Such an approach will reduce the large amounts of existing paperwork and will contribute to fewer errors in data transfer. Data integrity can be easily ensured prior to the award of a contract. Additionally, once a bidder's information is present in a database at DoD, the bidder will be required only to update the information (on subsequent bids) and there will be no need to resubmit all the data. Moreover, in the event of a mobilization, DoD would have a database of contractors' capabilities that could be quickly tapped. In the long-term, DoD can set up a network or a dial-in facility and bidders could enter the information directly in DoD's computers thus speeding up the response process on a solicitation. This concept of EDI between DoD and its contractors can be easily extended to vendors in the commercial world (see Figure 5) so that a truly responsive and JIT manufacturing textile-apparel complex can emerge.

4.4 APPAREL PRODUCT DATA EXCHANGE THROUGH STEP

The National Institute of Standards and Technology (NIST) has begun work on applying PDES concepts to the apparel industry. As the first step, an Apparel Pattern Information Model (APIM) has been developed to illustrate the feasibility of extending STEP to include apparel pattern data. A neutral file format for exchanging two-dimensional apparel pattern data between different marker making machines has been developed [17, 21]. Efforts are now being directed towards a full-fledged APDES (Apparel Product Data Exchange through STEP) effort that will include three-dimensional garment models, linkages to textile, anthropometric and other data related to the life-cycle of the product. AMA is being used for developing APDES application protocols.

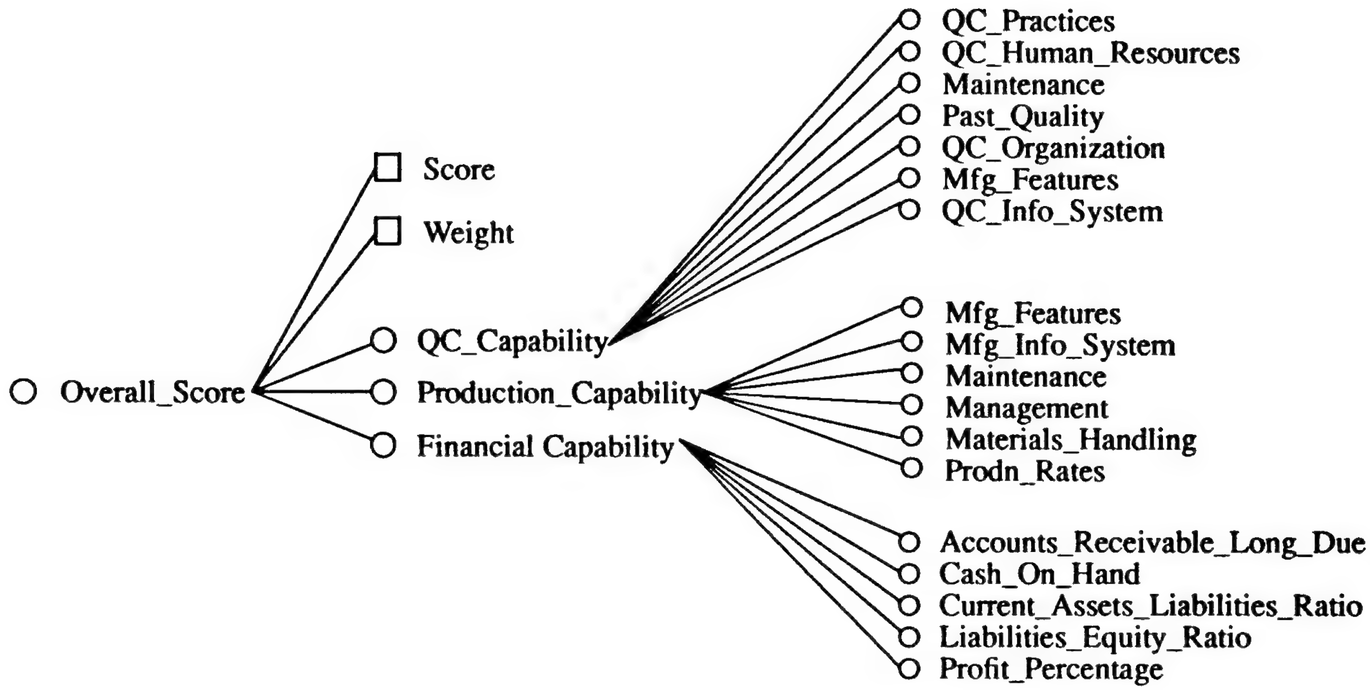

Figure 8. Decomposition of the Class *Overall_Score*.

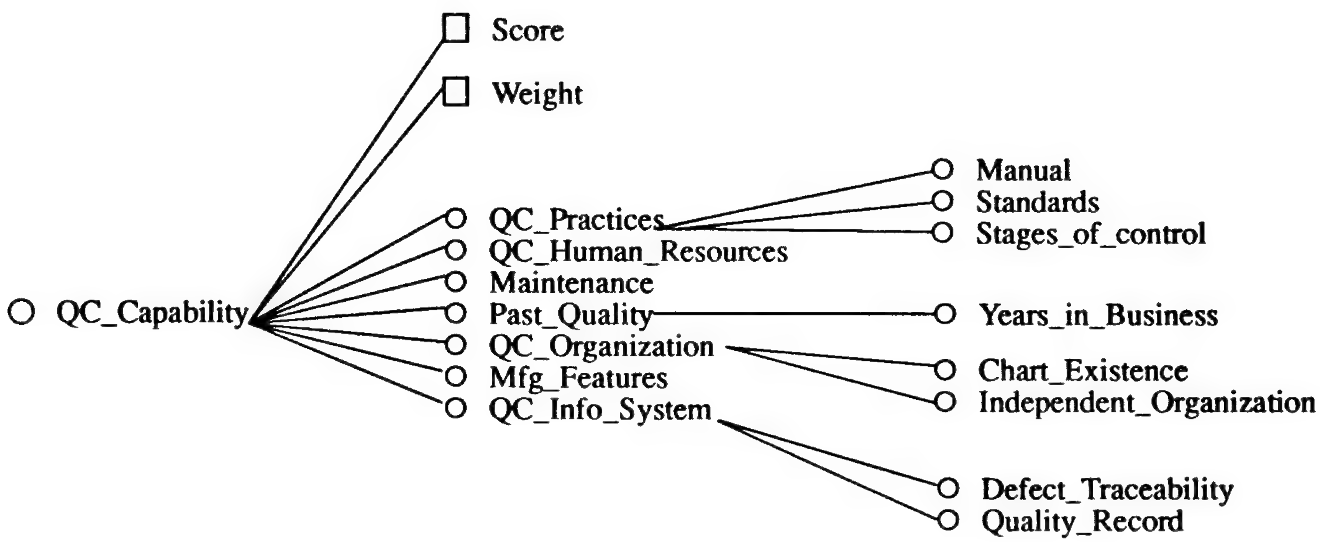

Figure 9. Decomposition of the Class *QC_Capability*.

4.5 POTENTIAL AREAS FOR FURTHER RESEARCH

In this section, areas for further research and exploration to effectively utilize mechatronics in the textile-apparel complex are identified.

4.5.1 EDI and Distributed Design and Manufacturing. By embracing and applying EDI and advancements in communications technology, the textile-apparel complex can explore the concept of *distributed design and manufacturing.* In such a framework, companies will each specialize in one facet of the product life-cycle, but will work together in a conceptually integrated environment even if they are located in different geographic locations. For example, a design house can invest in state-of-the-art technology and develop design expertise (technical and human) that can be shared with several manufacturers. Since resources will be directed to a single area, expertise and market share can be quickly built by the design house. The design house may further choose to focus on one market segment.

For the manufacturer, the proposed framework will provide the ability to pick and choose from a range of design houses. This flexibility in accessing a range of product designs will enable the manufacturer to effectively respond to the changing needs of the consumer and also to cater to a wider segment of the market. Likewise, by concentrating its resources on manufacturing, the company can afford to invest in state-of-the-art technology on the shop-floor, thereby improving the productivity and quality of the product. Issues related to hierarchical distribution of enterprise activities such as feasibility, logical divisions and economies of scale can be explored further.

4.5.2 CALS and Quick Response. As the textile/apparel industry embraces CDDAM philosophy, application of the CALS approach, viz., elimination of paper-based transactions and standardized data interchange throughout the product life-cycle, will become critical. Issues related to the creation of such a truly electronically integrated complex using the CALS methodology can be investigated.

4.5.3 Product Data Exchange Standards. The successful application of the concepts of DFM, CE and CDDAM necessitates the availability of a product's life-cycle date to all functions of the enterprise from design to markcting. This calls for the development of standards for representing product data so that any ambiguities in the design, manufacturing or other operations can be avoided -- the final product delivered will indeed be the product that was designed to be produced.

As mentioned earlier, AMA can serve as a good starting point for the apparel component of the product life-cycle data. The scope of AMA should be expanded to include the textile component of the life-cycle data. Once such an integrated information architecture is developed, the PDES/STEP methodology can be used to develop the appropriate application protocols and product data standards.

4.5.4 A Closed Loop Fabric Defects Recognition and Analysis System. As mentioned in Section 2.1.3, the fabric inspection system from ELBIT Vision Systems identifies defects on the fabric using a system of videocameras. At the other end, FDAS analyzes a defect, determines the cause for the defect in the upstream processes, and suggests appropriate remedies to prevent the defect from recurring. Since the classification schemes for the two systems are nearly identical,

issues related to integrating these two systems can be investigated. The ultimate objective will be to develop a closed loop fabric inspection and diagnosis system. Such an effort will further the concept of using sensory information from a process to effect changes on the machines electronically and without human intervention. Although the existing time scales in the process sequence (spinning and weaving) will not currently accommodate a learning and self-correcting system in practice, the area is worthy of further exploration and research.

4.5.5 Knowledge-based Systems for Process Planning and Scheduling. Process planning is a complex activity and the expertise of the process planner is invaluable to an organization. Since such expert planners are scarce, this area of enterprise activities is a potential domain for the application of KBS technology. An intelligent process planner that also effectively utilizes the distributed databases in the enterprise can be developed.

Traditionally, optimization tools such as linear programming have been used in the production planning and scheduling functions of the manufacturing enterprise. However, such purely algorithmic approaches to optimization, do not account for some of the realities of the manufacturing shop floor operations. Constraints are not always linear, and schedules are frequently modified to accommodate changing product demands and availability of resources (operators, materials and machines). The individual's experience and expertise greatly influence both the way the function is carried out and the resulting schedule. While the task itself is fairly well-defined, there is generally a shortage of experienced planners, thus making this task but one of many suitable candidates for the development of a KBS.

4.5.6 Fuzzy Logic Systems. At ITMA '91, Tsudakoma demonstrated a prototype *Fuzzy Logic Expert System* for the air-jet weaving machine. In this system, the main nozzle pressure setting is regulated based on integrating the information monitored on filling arrival time, loom stop data and fabric quality data. This type of integrated control leads to better accuracy and reproducibility. There is potential for similar applications of fuzzy logic concepts in the textile-apparel complex.

For example, in dyeing, the expert's opinion that the fabric has been dyed to the *right* shade is the outcome of a complex knowledge processing task that cannot often be encoded in black and white. Adjustments to the dyebath to ensure the right shade involve a multitude of interacting parameters and the resulting control decision (e.g., to add a certain amount of a specific color to the bath) is based on an integrated view of these parameters. Thus, there is scope for applying the principles of fuzzy logic to develop controllers for monitoring and regulating the shade during dyeing. Product design, production forecasting and style projections are other potential areas for the application of fuzzy logic in the textile-apparel complex.

In summary, the textile-apparel complex is a fertile area for the application of the principles of mechatronics.

5. Conclusions

The key to operating successfully in the global market lies in the effective management of physical and information entities in the textile/apparel enterprise. From the earlier discussion it is clear that mechatronics is being applied in the textile-apparel complex, albeit under different names, for ensuring a smooth and controlled flow of products and information in the enterprise.

The role and scope of mechatronics in textile-apparel production systems have been discussed. Specific examples have been presented to illustrate the applications. Concepts of information engineering, electronic data interchange and knowledge-based systems technology and their relevance to the textile-apparel complex have been discussed with specific examples. Major research efforts including the development of an enterprise architecture, knowledge-based systems and product data standards have been discussed. Finally, potential areas for further research and exploration in areas ranging from application of CALS to fuzzy logic have been presented.

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AEIS - Apparel Enterprise Information System

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Apparel Enterprise Information System (AEIS) is a relational database system developed in Paradox for Windows. It is based on the Apparel Manufacturing Architecture (AMA).

1.0 Need for Apparel Enterprise Information System

Today, any commercial enterprise faces increasing challenges to compete successfully in the global market. This is particularly true of an apparel enterprise because of the complex set of activities involved in it. To meet the competitive challenges, an apparel enterprise should possess the following:

- Quick response capability
- Flexibility
- Integration

Quick response capability enables shorter cycle time from the design of the product to its final delivery; flexibility provides the ability to produce small batches of a variety of products; integration implies coordination of not only all the sub-systems of the enterprise but also with customers, suppliers, etc.

Information is vital for an enterprise to achieve quick response capability, flexibility, and integration. The ability to access information when needed gives an organization a decided edge over its competition. However, the control and coordination of information by different sub-systems of an enterprise are as important as access to information.

To achieve these capabilities, the information system should ensure that

- All sub-systems of the enterprise have timely access to information whose integrity is assured.

- The flow of information between sub-systems and information processing across sub-systems is finely coordinated.

Design of information systems should consider the following:

- the various functions involved in the working of an enterprise.

- the information needs of the functions.

- information sharing between the functions.

- the dynamic interaction between them.

1.1 Apparel Manufacturing Architecture and RDBMS

AMA incorporates the functions, information and dynamics in an apparel enterprise [1]. Thus, it can serve as an ideal framework for developing an information system for an apparel enterprise.

A relational model is the most popular model underlying present day commercial databases [2]. The basic elements of the relational model are *entities*, *attributes* and *relationships*. The model is based on the notions of "sets" and "relations". In this model, *tables* are frameworks for representing entities, with the entity's attributes represented as *fields* of the table. Each individual record represents an entity. Sets of records represent entities of the same type. Each member of a set is uniquely identified by one or more fields (a single *primary key* or a *composite key*). The relationships between sets are identified through equality of values for a common field between sets.

There are some constraints imposed on a relational model to ensure integrity and to avoid update anomalies. This is achieved by a process called *normalization*, which ensures that the database conforms to these constraints [2]. Normalization ensures that the attributes are defined in such a way that the database has the appropriate number of entities and attributes. When referential integrity is established, no data can be entered in a child attribute when it does not figure in the parent entity. Also, any changes made to the attribute in the parent entity percolate down to all the child entities.

2.0 Apparel Enterprise Information System (AEIS)

Apparel Enterprise Information System (AEIS) has been developed in Paradox for Windows and consists of 112 entities, which represent the entities in the AMA Information Model. AEIS has 38 forms which capture the various details in an apparel enterprise.

AEIS offers a powerful mechanism to monitor and update the information on the various activities in the enterprise.

Since the total information to be captured is large, the information has been split into manageable units. Also, not all of the information is relevant to everyone in the organization. The total information can be classified by the functional areas of the organization and by the role each area plays in the product life cycle.

AEIS has various menu choices to enable the user to retrieve information about any aspect of an Apparel Enterprise. The menu choices are classified based on the various phases in the apparel product life cycle - Product Design to Marketing.

The various options in the menu (shown in Table 1) corresponding to the life cycle are:

- Specifications
- Pre-Production
- Production
- Marketing

The two other choices (shown in Table 2) are:

- Retrieve Information for
- Get AEIS Help for

2.1 Working with AEIS

This section describes how to work with AEIS utilizing its full capabilities. It is very easy to add data to the existing database and also to retrieve information from the database.

AEIS retrieves information in two modes:

1. Comprehensive mode; and

2. Selective search mode.

2.1.1 Comprehensive mode

When the user enters AEIS, the menu choices in Tables 1 and 2 are displayed. This is shown in Figure 1. If any of the menu choices in Table 1 is selected, the total information available in AEIS is retrieved and displayed. This is the Comprehensive mode. For example, if all the details pertaining to Pattern Grading need to be retrieved, the Pattern Grading option in the Specifications menu should be selected. This screen along with the answer table pulled up by AEIS is shown in Figures 2-5.

2.1.2 Selective search mode

Figure 6 shows the procedure for retrieval of information in Selective search mode. Table 2 shows "*Retrieve Information For*" as one of the menu choices and it has further options. When one of these options is selected, AEIS will prompt the user for an input. For example, if the user is interested in knowing the various details of the activities for a given Plant Code, the *Plant Code* option must be chosen and AEIS will prompt the user

Detailed menu selections available in AEIS

TABLE 1 **AEIS Menu Choices and the Apparel Product Life Cycle**

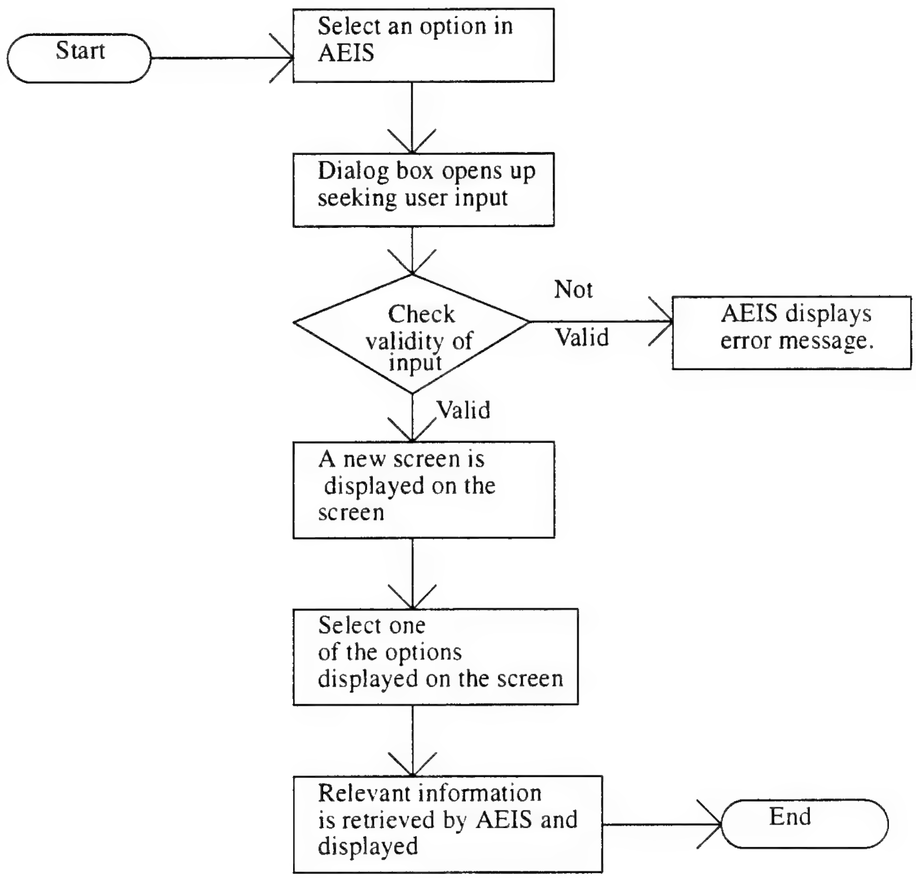
Specifications	Construction Detail
	Pattern Description
	Fit and Grading Tables
	Sample Garment Description
	Material Description
	Production Garment Description
	Assignment of Fabric Dependent Construction Details
Pre-Production	Product Development and Description
	Process Planning
	Quality Control
	Production Planning
	Material Procurement
	Marker Making
	Cut Order Planning
	Cutting Room Scheduling and Control
	Cut Package Preparation
	Sample Production Scheduling
Production	Mfg. Equipment Capability
	Mfg. Resources - Equipment
	Mfg. Resources - Human
	Mfg. Plant Scheduling
	Mfg. Resource Assignment
Marketing	Sales Program Description
	Customer Interaction
	Finished Goods Warehousing
	Shipping Order Description
	Packing and Shipping

Detailed menu selections available in AEIS

TABLE 2 **Menu Choices - For retrieval of Information and Help**

Retrieve Information For	Style
	Customer Code
	Production Order Number
	Plant Code
	Shipping Order
AEIS Help	What is AEIS
	How to use AEIS
	How to use "Retrieve Information For"
	Data entry for the entities
	How to construct a new query
	Get AMA_AEIS entity details
	Get names of forms and queries in AEIS

Figure 6 Information Retrieval Process in Selective Search Mode



to input the Plant Code details. A similar dialog box will pop up for the other menu options under "*Retrieve Information for*" menu choice. This is the Selective search mode. The sequence of screens when this mode is chosen, is shown in Figures 7-11.

2.1.3 How to add new data in AEIS

Data is stored as records in the various tables. Each table in AEIS corresponds to an entity in the AMA Information Model. Attributes are represented as fields in the various tables. The first step, in adding new information to AEIS, is to identify the entities affected by the information. By opening the appropriate tables, the information can be added easily. The default mode for entering data is the *table* mode. But when the number of attributes is very large, the *form* mode is a more convenient mode to enter data. It is possible to toggle between the table and the form modes by pressing F7.

2.1.4 How to modify the existing forms

AEIS uses the $IDEF_1X$ format for display of the information requested by the user. The information displayed corresponds exactly to the AMA Information Model (See Figure 11). The form names in AEIS correspond to the views in the AMA Information Model. The information displayed is in the *Form View* mode, which is the default mode. By pressing F8, the designer can enter into *Form Design* mode and change the information display as needed.

2.1.5 How to modify the existing entities

This can be done by using FILE/ RESTRUCTURE option in Paradox for Windows and modifying the entity as desired.

2.1.6 Slide Show of AEIS

A slide show providing a step-by-step introduction to AEIS has been developed in Freelance Graphics.

2.1.7 How to modify the existing entities

The existing entities in AEIS can be modified by using FILE/ RESTRUCTURE option in Paradox for Windows and modifying the entity as desired.

2.2 Concluding Remarks

AEIS is a powerful tool to monitor the various activities in an apparel enterprise throughout its product life cycle. Based on AMA, it is comprehensive in its information content and can be customized to meet the specific needs of an organization. It is also possible to set up AEIS as a distributed database. This requires the network version of Paradox for Windows.

2.3 Acknowledgment

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This slide shows the zero level diagram of AEIS. This is the screen on display when the file AEIS.fsl is opened in Paradox for Windows.

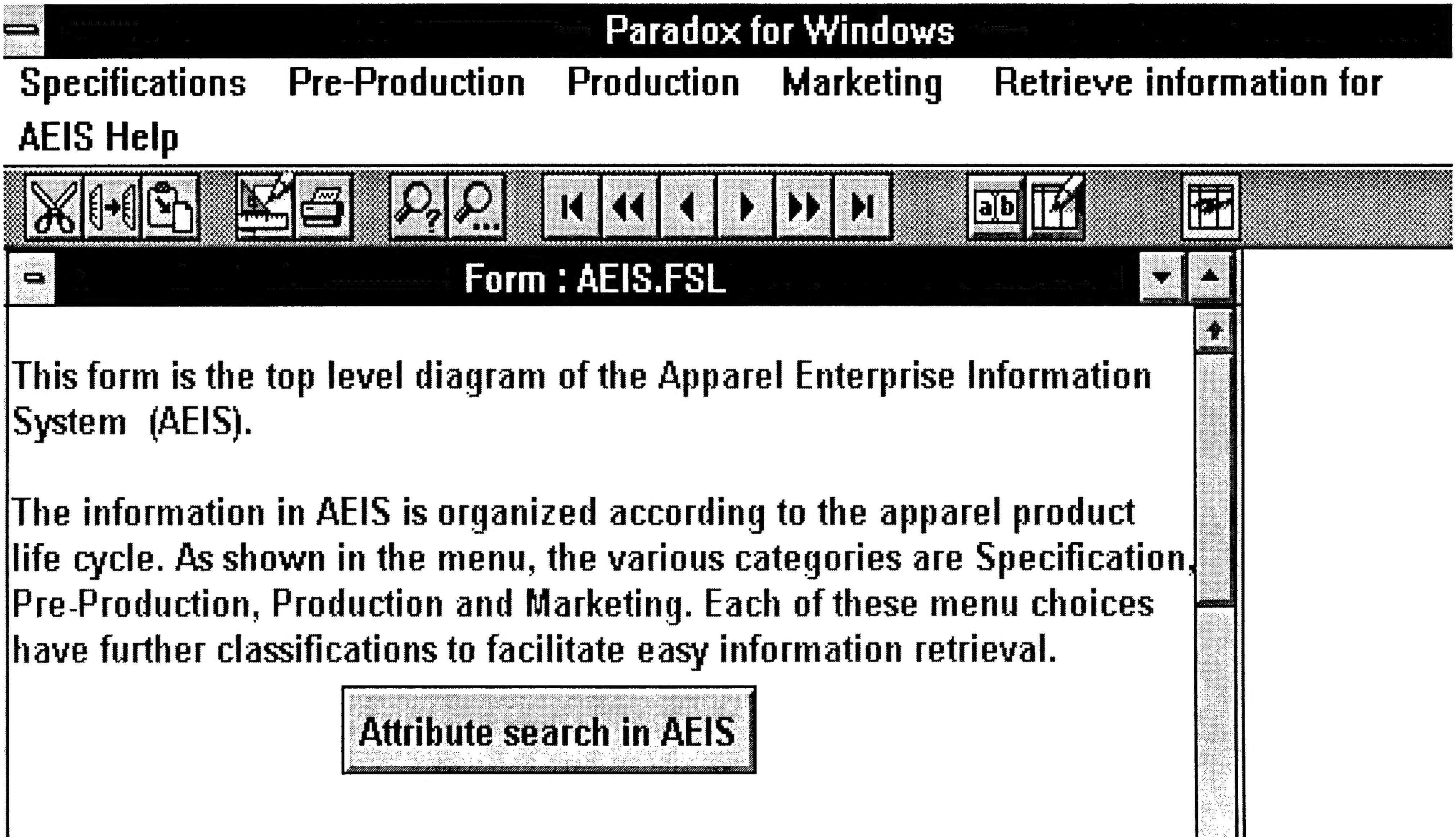
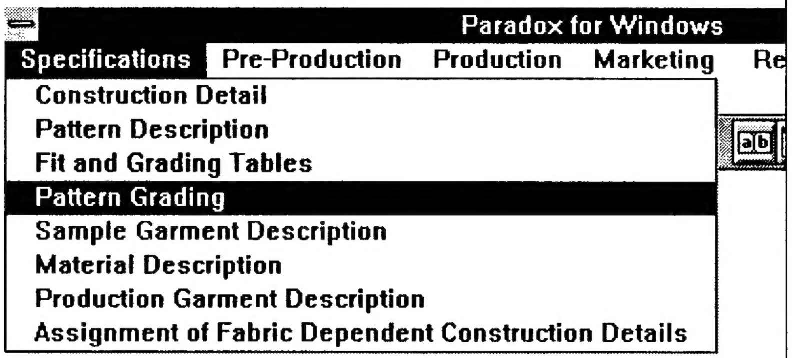


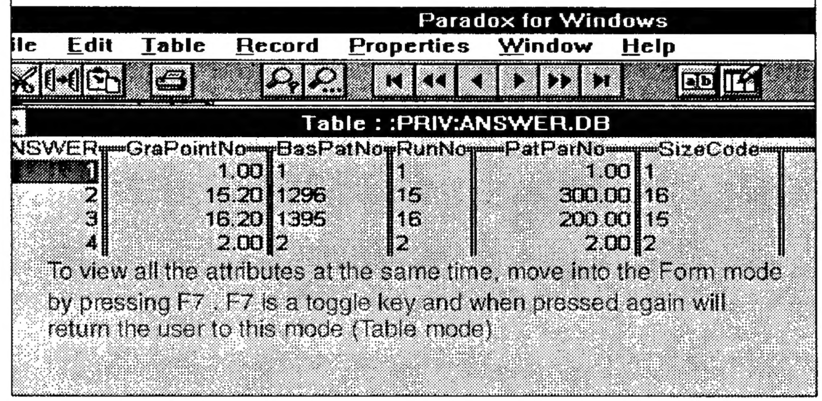
Figure 1

Figure 1

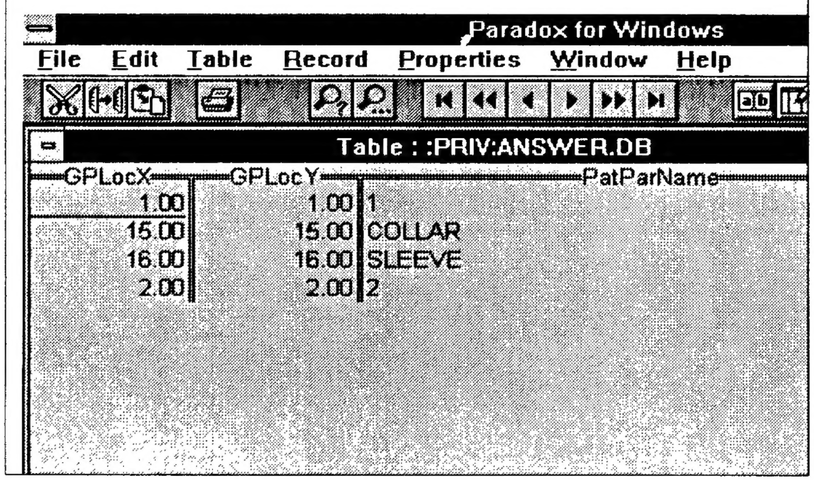
Pattern Grading under Specifications menu is being selected.



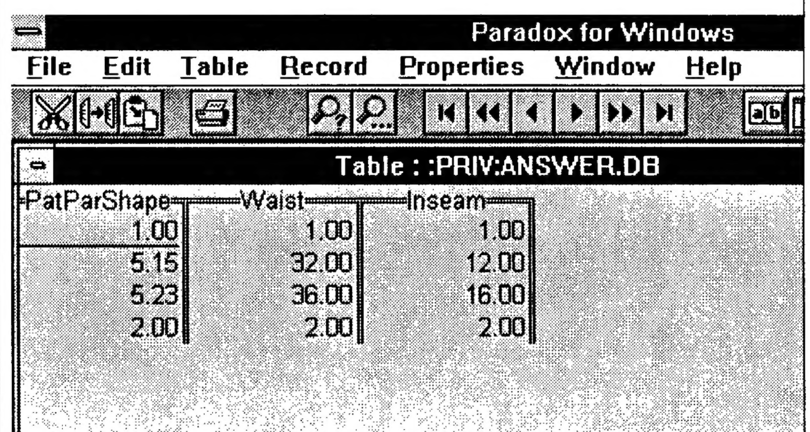
The results of the selection of Pattern Grading are displayed in this slide. Only part of the answer table is on view in this slide. The next slide shows the other half of the table.



This slide shows some more details in the answer table pulled up by AEIS.

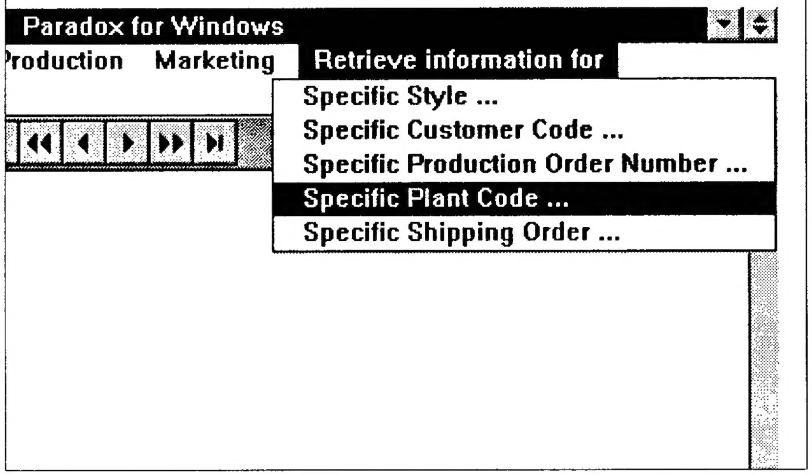


This slide shows the remaining details in the answer table pulled up by AEIS.

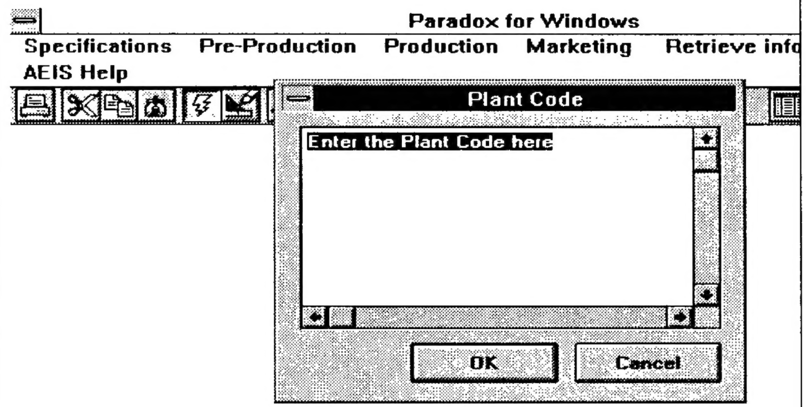


Figures 2-5

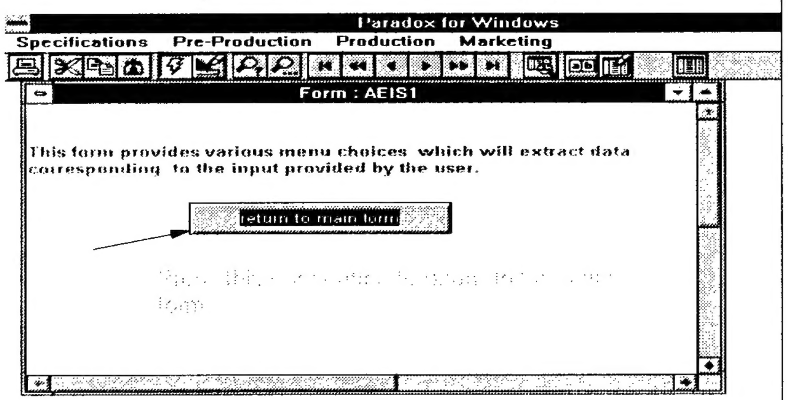
This slide shows "Specific Plant Code" being specified.



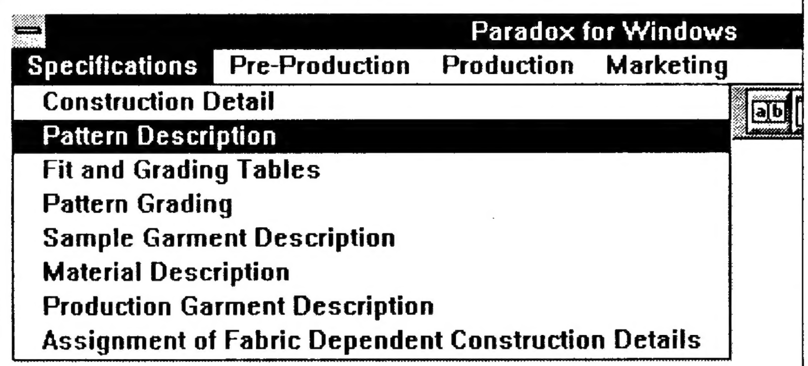
This slide shows the dialog box which pops up prompting for an input from the user. A similar dialog box will pop up for other selections like style # , production order #.



The form pulled up by AEIS based on the input given in previous slide is displayed.



This slide shows Pattern Description (under Specifications) being selected. The result of this selection is shown in the next slide.



Figures 7-10

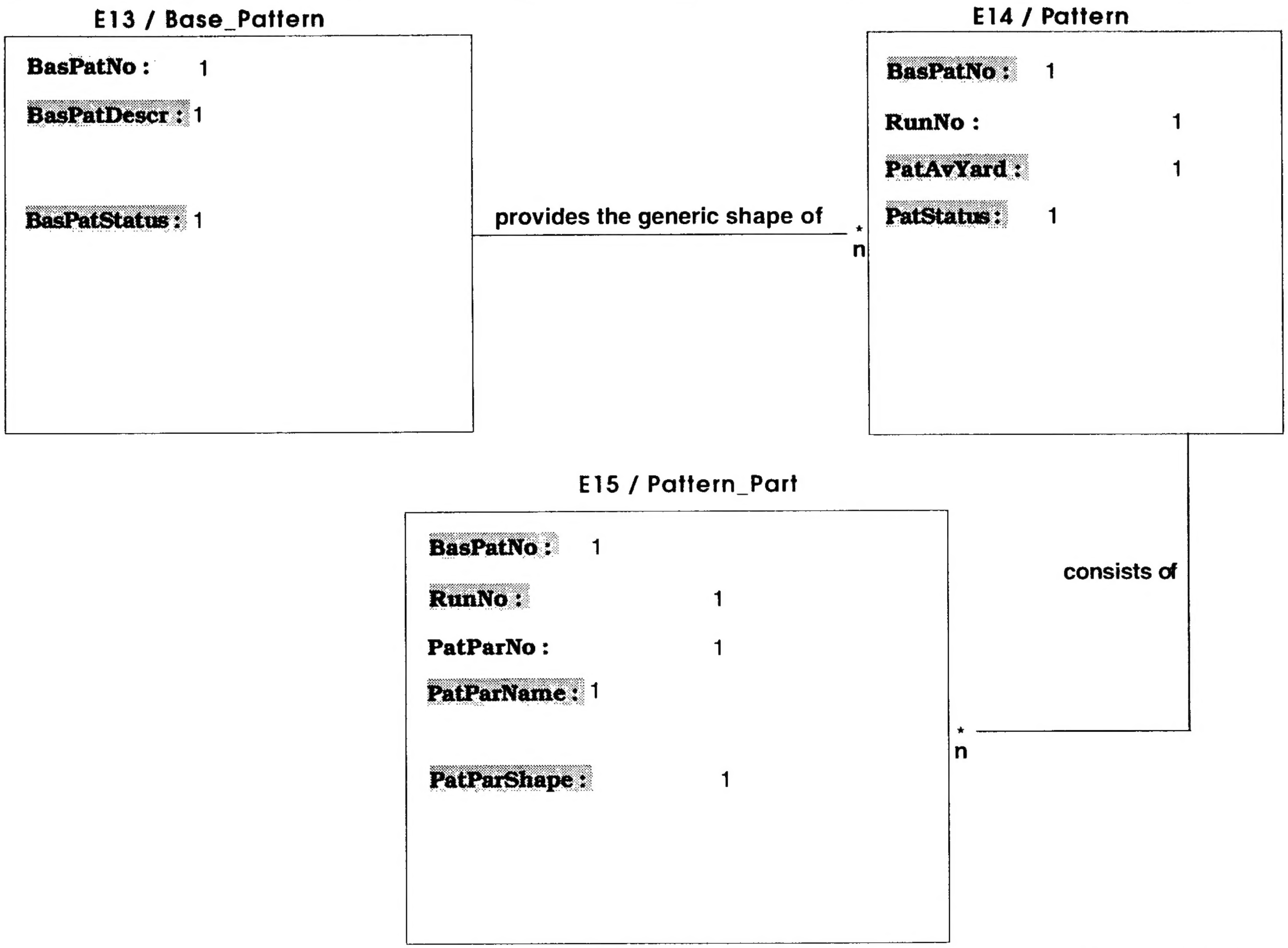


Figure 11

FORM : F110 - 0